1983 and 1984 Invertebrate Management Advice, Pacific Region

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Canadian Manuscript Report
of Fisheries and Aquatic Sciences No. 1848

November 1985

1983 AND 1984 INVERTEBRATE MANAGEMENT ADVICE, PACIFIC REGION

by

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ABSTRACT

Jamieson, G. S. (Editor). 1985. 1983 and 1984 invertebrate management advice, Pacific Region. Can. MS Rep. Fish. Aquat. Sci. 1848: 107 p.

Biological advice given to resource managers by research scientists and biologists in November of both 1983 and 1984 is presented as a series of documents. Some other advisory manuscripts have been published elsewhere. The topics discussed here include a stock assessment of Barkley Sound shrimp, the effect of growth rate variability on minimum size restrictions for prawns (Pandalus platyceros), on-going scallop hatchery studies, a stock assessment of intertidal clams on Savary Island, ghost fishing by lost Dungeness crab (Cancer magister) traps, crab movement in the Fraser River delta, crab gear selectivity studies in Departure Bay, and an evaluation of geoduck (Panope abrupta) survey methodology.

RÉSUMÉ

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On présente dans une série de documents les conseils en biologie donnés à des gestionnaires de ressources par des chercheurs scientifiques et des biologistes en novembre 1983 et 1984. Certains autres manuscrits de consultation ont été publiés ailleurs. Les sujets abordés ici comprennent une évaluation du stock de crevettes du détroit de Barkley, l'effet de la variabilité du taux de croissance de la crevette rose (Pandalus platyceros) sur les restrictions quant à la taille minimale, des études permanentes sur des écloseries à pétoncles permanent, une évaluation du stock de palourdes intertidales de l'île Savary, la pêche par cages à crabe dormeur (Cancer magister) abandonnées, le mouvement du crabe dans le delta du Fraser, des études de sélectivité des engins de pêche au crabe dans la baie Departure et une évaluation de la méthode de dénombrement des glycimères (Panope abrupta).

INTRODUCTION

The Fisheries Research Branch in the Pacific Region provides biological and scientific advice for managing, protecting, and developing the region's freshwater and marine resources. It consists of a number of sections, one of which is the Shellfish section, and specific functions and areas of responsibility of this section are as follows:

1. to undertake research on the distribution, life history, ecology, physiology, and behaviour of commercial and potentially commercial invertebrate and marine plant species;

2. to carry out resource surveys and the sampling of commercial catches for stock assessments of invertebrate and marine plant species;

3. to participate in research on the impact of natural and man-induced factors on the habitat of invertebrate and marine plant stocks;

4. to maintain fishery data bases and to develop analytical methods, including the use of theoretical models, to achieve the above;

5. to provide biological management advice to the management biologists and senior management, and to communicate research results to fishermen, industry, and the scientific community.

The first two manuscript documents on pandalid shrimp were presented to resource managers in November, 1983, whereas the remaining manuscripts were presented in November, 1984. This collection of manuscripts, along with Sloan (1984), Robinson and Jamieson (1984), Boutillier et al. (1984, 1985) and three reports in preparation, is the scientific basis for invertebrate fisheries management advice given in 1983 and 1984 by the Shellfish Section, Fisheries Research Branch, in the Pacific Region.

As such these documents address the issues of the day in the time frames required and are not intended as definitive statements on the subjects addressed. Rather, they should be considered as progress reports on ongoing investigations. Manuscripts presented in 1982 are presented in Jamieson (1984).

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BARKLEY SOUND SHRIMP FISHERY
RESULTS OF THE 1982-83 LOG-BOOK AND CATCH SAMPLING PROGRAM

by

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ABSTRACT

Recent requests for increased participation by fishermen in the Barkley Sound shrimp trawl have resulted in evaluation of options. A logbook and catch sampling program were recently initiated, but logs proved unusable for analyzing stock size because of poor fishing success. Catch sampling data has provided information on composition and exploited species size frequencies by area.

If a quota management is adopted, conservative quotas are initally recommended because of the limited data presently available.

Key words: Barkley Sound, beam trawl, shrimps, data-base, quotas

INTRODUCTION

The Barkley Sound beam-trawl shrimp fishery began in 1959-60. Peak landings of >455 t were obtained in the early 1970's. Starting in 1973, this fishery began to decline and all hut vanished because of anecdotally reported economic reasons. In 1980, interest in the fishery began to revive and a small fleet of local beam-trawlers fished Trevor Channel. In the fall of 1982, a permit fishery was developed for this region because of persistent requests to allow local non-S-tab fishermen to participate in an apparently underutilized fishery which required greater daily total landings for profitable rationalization.

To ensure that this fishery developed in a controlled manner, certain restrictions were appended to each permit:

1. Permit boats were not allowed to fish in traditional "S" tab fishing grounds in Trevor Channel (Fig. 1).

2. An initial precautionary quota of 113 t was established for the period from April 1, 1982 to March 31, 1983.

3. Permit holders were required to submit a log-book as a condition of maintaining their right to fish.

This report summarizes efforts to develop a data-base from which to delineate population parameters, which would be used to develop future management strategies for this fishery.

METHODS

The data was collected from two sources: a log-book program (mandatory for permit boats and voluntary for S-tab vessels), and an on-board observer catch sampling program.

The main objective of the log book program was to test the feasibility of using CPUE as a stock assessment tool.

The main objectives of the catch sampling program were to collect information on species assemblages, availability functions, growth rates, and age class frequencies.

CATCH SAMPLING PROCEDURES

Initially, an attempt was made to sample the fishery at least once a month. When the permits were extended, prior manpower commitments reduced this sampling intensity to once every 3-4 months.

Total weight of the catch in each haul was estimated by the vessel captain as the catch was brought aboard. Where practical, the catch was then sorted by species and weighed to the nearest 0.1 kg. "Floaters" (e.g. hake, pollock, midshipman etc.) were removed before the net was taken aboard (codends are usually equipped with a "zipper" for this purpose), and their weight estimated. When abundance of non-target species was minimal, only an indication of their presence was noted on the haul card.

All shrimp were sorted by species and weighed to the nearest 0.1 kg. In normal commercial fishing, only the larger prawns (Pandalus platyceros) and sidestripe (Pandalopsis dispar) are separated from the pinks; the smaller specimens of these species are sold with the pinks (Pandalus jordani and P. borealis) at a lower price. When large quantities of pink shrimp were caught, their total weight was estimated by counting the full baskets (@ 18 kg basket-1) and weighing any partial remainders.

Once the shrimp catch was sorted by species a random sample of pinks (2 kg sample) was put into ziplok bags, labelled, and retained for analysis at the laboratory. A random sample of prawns (about 300 haul-1 and at

least 1000 from each of the areas sampled during each trip) was weighed, sexed, and measured (carapace length (CL)). If time permitted, sidestripe shrimp were similarly processed. Occasionally, time constraints determined that only the larger specimens of prawn and sidestripe were measured on board while the smaller specimens were retained for analysis at the lab.

RESULTS AND DISCUSSIONS

Log book

The log book data collected was for the periods Dec 1, 1982 to March 31, 1983, and April 1, 1983, to June 4, 1983. This data was collected only from the mandatory log book program for permit vessels as no voluntary log book information was submitted.

Of the permit boats, log book coverage was obtained from the following vessels: COLUMBUS, FISHTAIL, ISKUM #1, MUSTANG, and SUNDOWN .

An analysis of stock size using CPUE (effort was measured as kg hour-1 the gear was towed) regressed against the total catch proved unusable for both periods mentioned above. This was not unexpected since the total catches (all species combined) over these time-frames were very small, 1 and 7 t respectively.

This lack of fishing success, especially during the period from Dec 1 to March 31, was probably due to a combination of bad weather and inexperience.

CATCH SAMPLING

The results of the catch sampling are somewhat more informative, although still limited because the catches were often too small to get reliable samples.

Both log book and sample information revealed that the catch composition by species was as follows:

	Logbook	Catch sampling
Pandalus jordani (smooth pink)	83.0%	78.0%
P. platyceros (prawn)	3.5%	7.0%
Pandalopsis dispar (sidestripe)	13.5%	15.0%

The log book data tended to show a smaller percentage of sidestripes and prawns in the catch, which was to be expected since the smaller age classes of these species were not sorted from the smooth pinks when the catch was sold.

A preliminary analysis of the length-frequencies indicates that:

1. There were differences in average size and year class ratio in the catch between Pandalus jordani landings from Trevor Channel and those from Imperial Eagle Channel.

2. Juvenile (0+ yr) prawns are more prevalent in beam-trawl catches than prawn trap catches. Juvenile prawms may comprise as much as 75% of the total beam trawl prawn catch (Fig. 2), while prawns at this size and age are rarely encountered in the prawn trap fishery.

	Trevor Channel (March)				Imperial Eagle Channel (Feb.)			
P. jordani	n	CL (mm)	S.D.	%	n	CL (mm)	S.D.	%
0+	24	11.5	.7	1.2	-	-	-	-
1+	1589	17.3	1.4	79.7	242	17.6	1.1	31.1
2+	381	21.4	2.1	19.1	287	19.7	1.3	36.9
3+	-	24.4	2.7	-	249	23.0	1.5	32.0

QUOTA OPTIONS

In 1981 (Bernard 1982), two surplus production models (exponential and Schaefer) were fitted to the Area 23 saleslip data base for the years 1962 through 1971 (Fig. 3). The data was found to best fit the exponential model, with a resulting MSY of 313 t. Using this model, a comparison of CPUE for the years 1980, 1981, and 1982 against the U_{max} from the model suggests that Area 23 pinks and sidestripe stocks were strong, i.e. stock size was on the right hand side of the production graph. However, 1981 CPUE may be overly high because of offshore otter trawl landings mixed in with the beam trawl data.

If a decision is made to adopt an area quota, managers could opt for:

1. setting the quota near the MSY of 300 t for the period April 1, 1983 to March 31, 1984, or

2. setting the quota at a more conservative level, e.g. 113 t for the same time period. This precautionary level is recommended because of a concern about the quality of data to which the surplus yield models were fitted. The quota could be subsequently increased if 1983/84 log book and catch sampling data did not indicate that fishing was having adverse affects on shrimp populations in the area.

To improve the quality of future analyses, it is recommended that emphasis be given to:

1. collecting log book information from the S-tab voluntary log book program, and

2. collecting adequate samples of all species during the same time period from the two major fishing areas (Imperial Eagle Channel and Trevor Channel). This would permit a better comparison of growth rates of individuals between the two areas.

ACKNOWLEGMENTS

The authors wish to express their sincere appreciation to those Area 23 fishermen who cooperated with the program by supplying accurate and complete log books. We especially thank those who allowed us to sample aboard their vessels.

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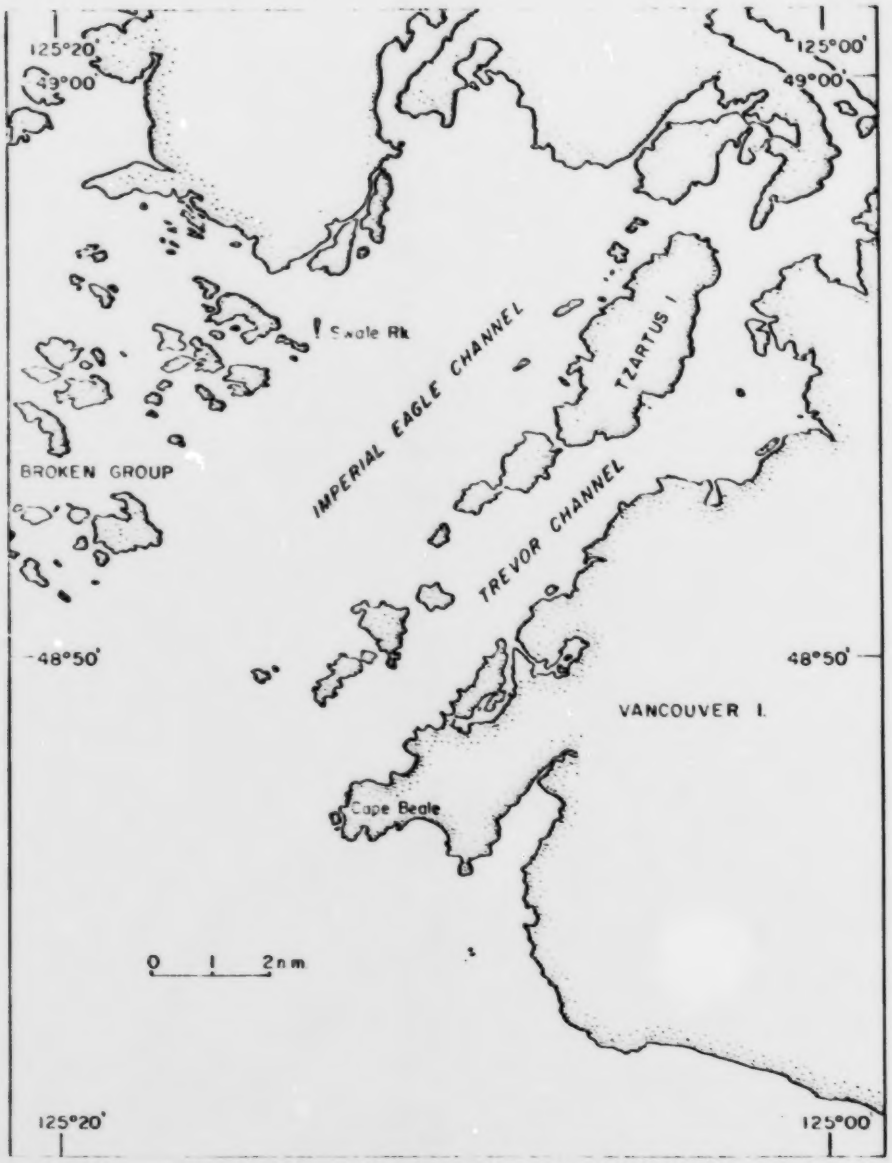


Figure 1. In the Barkley Sound beam trawl fishery for shrimp, Trevar Channel was closed to permit boats as it was the traditional "S" tab fishing area.

Figure 2. Carapace length frequency histogram of the prawn, Pandalus platyceros, catch from March 1983 beam trawl fishery. Juvenile 0+ prawns with a mean carapace length of 21.4 mm make up 75% of the catch.

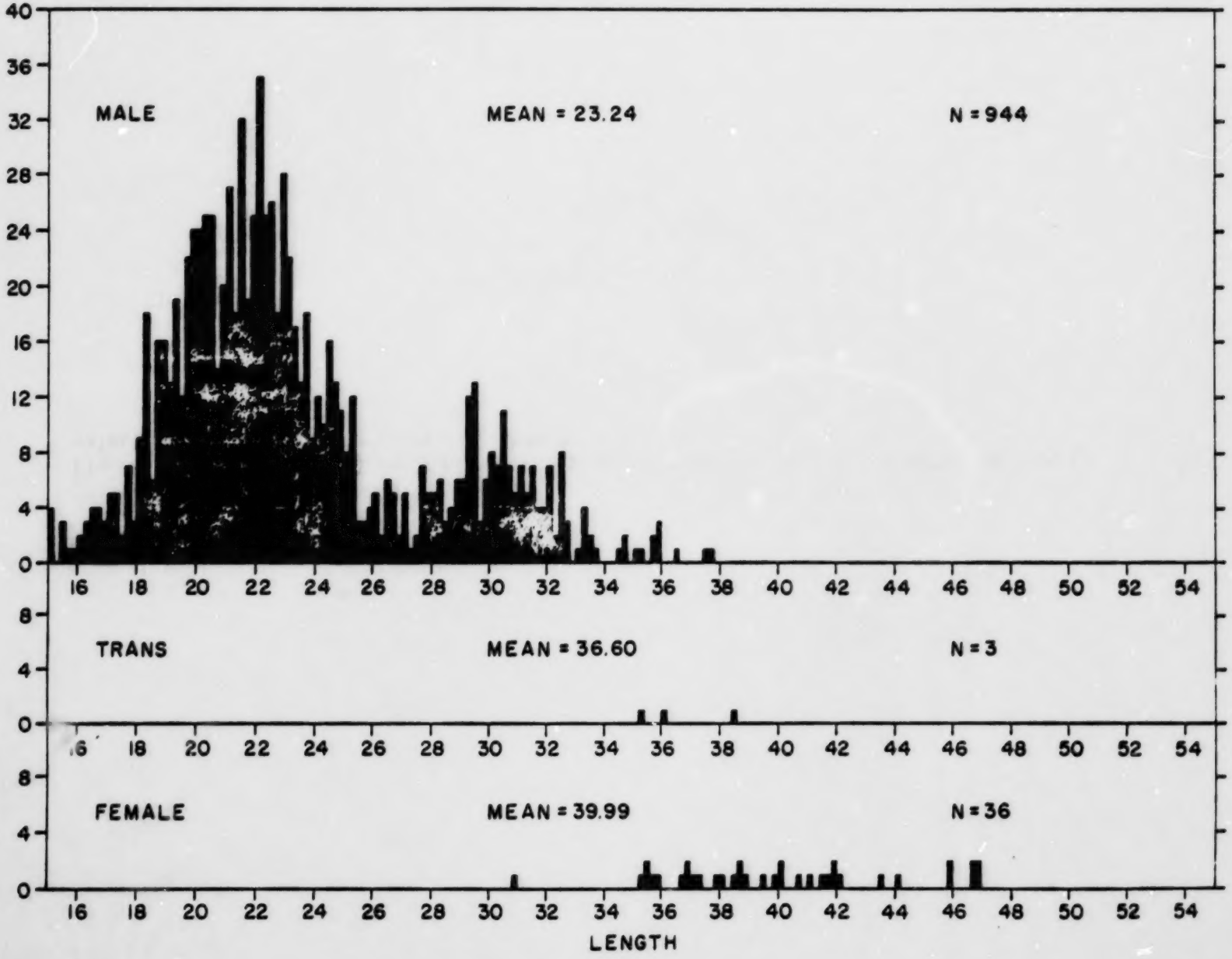
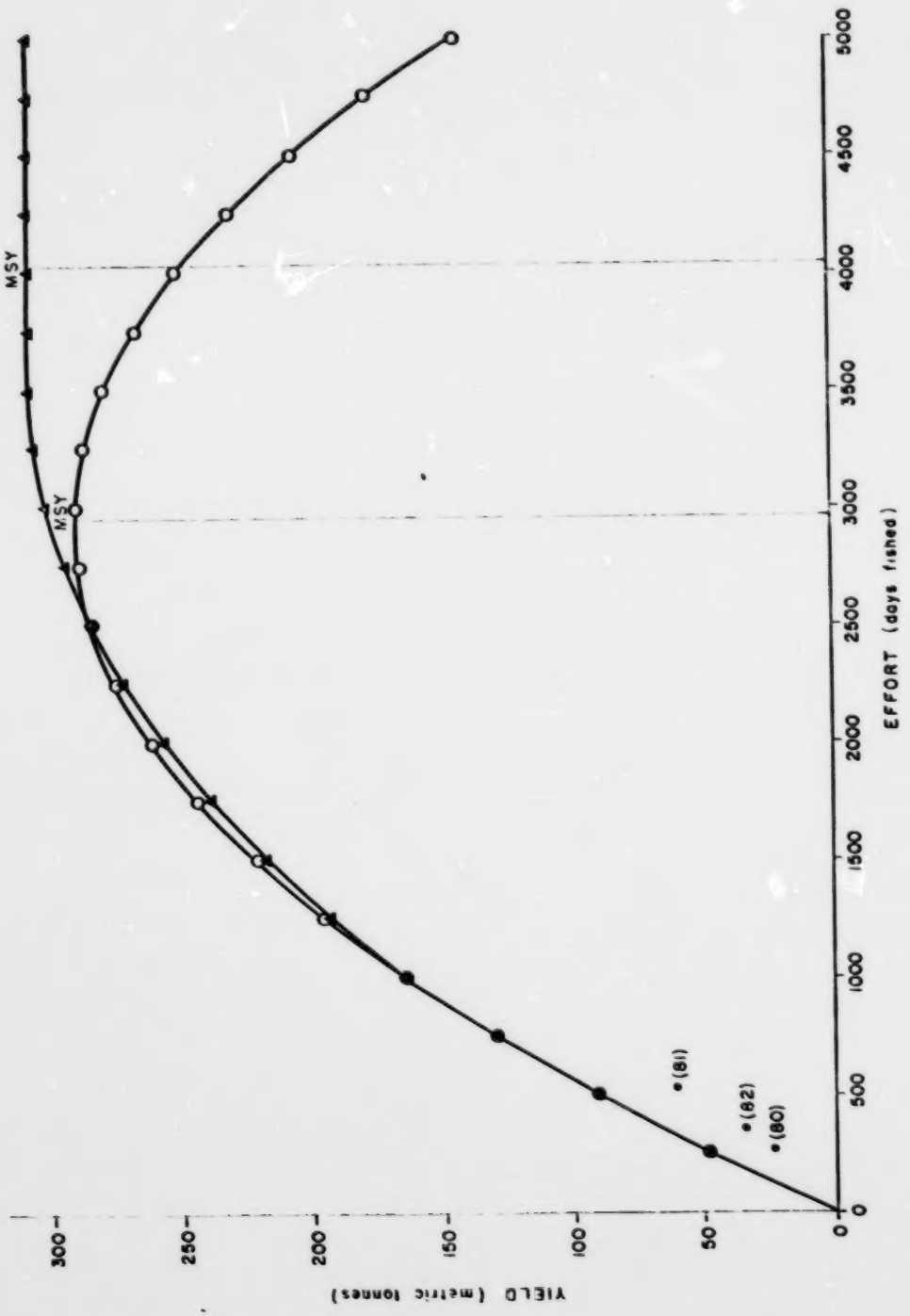

MALE
MEAN = 23.24
N = 944
TRANS
MEAN = 36.60
N = 3
FEMALE
MEAN = 39.99
N = 36
LENGTH

Figure 3. Exponential (Δ) and Schaefer (0) surplus production models fitted to the Area 23 saleslip data base for the years 1962 through 1971.


MSY
MSY
(81)
(82)
(80)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
EFFORT (days fished)
50
100
150
200
250
300
YIELD (metric tonnes)

EFFECT OF VARIABILITY IN GROWTH RATES ON MINIMUM SIZE RESTRICTIONS FOR PRAWNS (Pandalus platyceros)

by

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ABSTRACT

This paper deals with variability in prawn (Pandalus platyceros) growth rate and its implications in the implementation of minimum size restrictions. The benefits accrued from increasing age of first capture, from one year to two years were investigated using a yield-per-recruit model. A series of management options are suggested and discussed.

Key words: Pandalus platyceros, prawn, minimum size, growth rates

INTRODUCTION

The rationale for increasing age at first capture of prawns, Pandalus platyceros to two years old and the problems inherent in the establishment of such a regulation have been discussed (Boutillier 1984). This document was prepared to quantify one of these problems; variability of prawn growth rate between areas.

METHOD AND DATA

For the purposes of this analysis, all the prawn samples, from the commercial monitoring program collected during April in 1980-82 were examined to determine mean size (carapace length (CL)) and variance of 2 yr old animals. The month April was chosen as it is the approximate time of annual hatching and hence represents animals which are exactly 2 yr old. A total of 18 samples from 12 different areas were analysed for age and size using the Schnute-Fournier length frequency analysis (Schnute and Fournier 1980). In addition to mean CL, a lower size limit, < the size of 75% of the prawns in the sample, was also calculated. This lower limit was calculated from:

$$Y = \bar{X} - .674\ S$$

where Y is the lower size limit (this calculation assumes a normal size distribution),

$\bar{X}$ is the estimated mean carapace length of the age class,
S is the estimated standard deviation of the carapace length around the mean.

RESULTS OF VARIATION IN GROWTH RATES

Results of the analysis are presented in Table 1. Mean carapace length of 25+ month prawns for all 12 different areas ranged from 28.5 mm to 33.0 mm with an overall weighted average of 31.2 mm. The lower 75% CL confidence level for these same specimens ranged from 27.3 mm to 31.7 mm with a weighted average of 29.8 mm.

Rationale for size limits

Breen (1984) discusses the possible functions of a minimum size limit. The two major reasons for this type of regulation are:

1. to prevent lower yield harvesting practices which result when individuals are taken at too small an average size,

2. to act as a reproductive reserve for a population, in which a year class is protected for its first and/or second year as a mature functioning adult, before it becomes available to the fishery.

If a minimum size limit was implemented for prawns it would be justified only for the first reason cited. A minimum size limit to protect a reserve of breeding population would not be practical for this shrimp species, since individuals are protandic hermaphrodites and the breeding female component of the population is composed of the largest individuals in their final year of life. They usually die shortly after breeding, making a fishery confined to that life stage impractical.

Yield per recruit analysis

In the 1982 minimum size limit report (Boutillier 1984), when F was held constant at .041 monthly and age of first capture was increased from 13 to 25 months, total yield in weight decreased by 21.4%, dollar value increased by 5.1%, and spawning biomass increased by 18.8%. There were two problems with this earlier analysis which either substantially underestimated or made unclear the benefits of a regulation which increased age of first capture to 25+ months. The first problem, which may lead to an underestimate of benefits, was that analysis was based on availability functions where cohorts were not believed to be fully recruited to the fishery until they were 31 months old. This set of availability functions was derived from monitoring a prawn population in an experimental closed area. Analysis of catches from the commercial monitoring program empirically suggest that full recruitment to an

exploited fishery comes at a much earlier age. There could be a number of reasons for this apparent shift in availability, including: density dependent intraspecific competition between cohorts or targeting on juvenile rearing areas by the commercial fishery.

The second problem is that the benefit of a larger remaining spawning biomass is difficult to interpret and is not quantifiable.

In a re-analysis of the yield-per-recruit model, the availability function was adjusted to allow for full recruitment of exploited stocks at 21 months. A comparison of total yield and value was carried out for fishing strategies which ended up with the same spawning biomass. This more or less mimics what the present minimum spawner escapement management tries to accomplish.

In the re-analysis it was found that, in a fishery where the age at first capture is 13 months and monthly F was 0.045, resulting spawning biomass is similar to a fishery with a first-capture age of 25 months and a monthly F of 0.060. By increasing age of first capture to 25 months, total weight yield will increase by 4% and dollar value, resulting from harvest of higher quality prawns, will increase by approximately 46% assuming that the price differential used in 1982 (3 x yield of prawns $\geq$ 25 months and .75 x yield of prawn <25 months) is still valid.

MANAGEMENT OPTIONS

Results of increasing age of first capture to 25 months appears to be a positive regulation for the prawn fishery.

Bearing in mind that there are variations in growth rates between areas, options for implementation of a minimum size of regulation are:

1. Size limit restriction by area. This would require further sampling before recommendations could be made for all areas. It would also be difficult to enforce with the present management system.

2. A coast-wide minimum size limit. There are a number of alternative size limits which could be used, such as:

   a) the lowest minimum 75% confidence level = 27.3 mm: 93%-100% of age 2+ yr animals coast-wide would become available for harvest (average over the year 97%). However, age 1+ yr animals which should be protected will also be available at levels of 4%-93% over the year (average over the year 49%)

   b) the average minimum 75% confidence level = 29.8 mm. This would decrease the percent age 2+ yr animals available to the fishery over the year to 70.6%-99.7% (average 85.2%). This increase in minimum size limit would, however, reduce the availability age 1+ yr animals from .3%-70.6% (average 36%).

c) Higher minimum size limits are also options, with the understanding that, as size limit increases, availability of 2+ yr animals decreases and fewer 1+ yr animals are exploited.

Prior to implementation of any minimum size regulation, it will be necessary to determine how to measure headed prawns, to ensure that they meet a minimum size regulation and ensure that prawns <25 months old are released with minimal mortality.

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Table 1. Mean carapace length (mm) and lower 75% confidence limit by area from prawn samples collected during the commercial monitoring program in April.

Area	Date		CL	CL at age (y)		
	Month	Year		1+	2+	3+
Knight Inlet	Apr.	80	$\bar{x}$	23.3	33.0	42.2
			S.D.	.7	1.9	3.1
			75%		31.7	
Kingcome Inlet	Apr.	81	$\bar{x}$	24.1	31.4	37.4
			S.D.	1.3	2.0	2.7
			75%		30.1	
Tribune Channel	Apr.	81	$\bar{x}$	25.2	31.5	38.5
			S.D.	2.3	2.1	1.9
			75%		30.1	
Loughborough Inlet	Apr.	81	$\bar{x}$	19.4	28.5	37.7
			S.D.	2.0	1.7	1.5
			75%		27.4	
Lower Jervis Inlet	Apr.	81	$\bar{x}$	24.0	30.2	35.7
			S.D.	1.2	1.6	2.1
			75%		29.1	
"	Apr.	81	$\bar{x}$	24.6	32.1	40.1
			S.D.	1.4	1.8	2.3
			75%		30.9	
Sechelt Inlet	Apr.	80	$\bar{x}$	25.6	30.4	36.7
			S.D.	1.7	1.6	1.6
			75%		29.3	
"	Apr.	81	$\bar{x}$	21.8	29.6	36.5
			S.D.	2.0	2.1	2.2
			75%		28.2	

Table 1 (cont'd)

Area	Date		CL	CL by age (y)		
	Month	Year		1+	2+	3+
Alberni Inlet	Apr.	81	$\bar{x}$	24.7	32.8	40.0
			S.D.	1.2	1.8	2.5
			75%		31.6	
Alberni Inlet	Apr.	81	$\bar{x}$	23.7	32.9	38.9
			S.D.	2.4	2.8	3.1
			75%		31.0	
Muchalat Inlet	Apr.	81	$\bar{x}$	24.8	30.7	38.5
			S.D.	1.5	2.3	3.2
			75%		29.1	
"	Apr.	81	$\bar{x}$	23.6	32.4	39.1
			S.D.	1.2	2.0	2.7
			75%		31.1	
	Apr.	82	$\bar{x}$	25.7	30.8	37.7
			S.D.	2.3	2.7	3.0
			75%		29.0	
Tlupana Inlet	Apr.	80	$\bar{x}$	22.2	30.5	38.3
			S.D.	2.3	2.8	3.3
			75%		28.6	
Tahsis Inlet	Apr.	81	$\bar{x}$	23.0	33.0	37.8
			S.D.	1.0	2.0	2.9
			75%		31.7	
Howe Sound	Apr.	80	$\bar{x}$	23.9	33.3	40.0
			S.D.	2.3	2.4	2.4
			75%		31.7	
"	Apr.	82	$\bar{x}$	24.9	31.7	39.5
			S.D.	1.9	2.4	2.8
			75%		30.1	

CRAB GEAR SELECTIVITY STUDIES IN DEPARTURE BAY.

by

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ABSTRACT

A study conducted in Departure Bay, British Columbia measured size-selectivity on Dungeness crabs (Cancer magister) of three trap types, and the relative performance of trawl and SCUBA transect surveys. The three trap types were commercial style, commercial style with no escape ports ('research traps'), and commercial style with no escape ports and a reduced tunnel entrance ('modified research traps'). Trawls and the SCUBA transects were not successful because of low crab density and scarcity of small crabs in the study area. Among the traps, catch rate of males differed in the order commercial > research > modified research; but these differences were not significant. For females, the order of catch rates was the reverse, and differences were significant. These differences are consistent with trap saturation effects. An experiment was carried out to determine whether low numbers of crabs already caught have a positive or negative effect on further entry to the trap; both large and small males appeared to have a strong negative effect on total catch rate. Bait efficiencies were compared among several types of baits. Squid was found to be more effective than herring, and herring in bait jars was more efficient than herring on hooks within the traps.

INTRODUCTION

The purpose of this study was to develop selection curves for commercial and modified Dungeness crab (Cancer magister) traps. Commercial traps have escape ports to allow sublegal crabs and females to escape, reducing handling mortality. Sublegal crabs are those less than 165 mm total carapace width, and include nearly all females. Traps modified for research purposes either have no escape ports or have the escape ports wired over, and have been used in several projects examining the population biology of Dungeness crabs. Size selectivity of trap gear is well documented (e.g. Diamond 1983). Since size frequencies of crabs are frequently obtained from

measuring crabs in commercial catches, establishment of relative selection curves is necessary so that data obtained from research and commercial gear types can be compared.

The original experimental design was to compare size frequencies of crabs caught in several trap types, crabs caught in a small mesh trawl in the same area, and crabs caught by divers herding crabs from a known area along an underwater drift fence. This did not prove feasible, for reasons discussed below, but catch rates and sizes caught were compared among three different trap types. We also present information on efficiency of three bait types, and describe the results of experiments to test the effect of low crab densities within traps on the rate of entry of crabs to a trap.

Departure Bay was chosen as the study site because a commercial fishery operates in the Bay, with up to 4 vessels fishing with traps set on longlines; and because the Bay could support a field study at low expense because of its proximity to the Pacific Biological Station.

GENERAL METHODS

All field work was carried out in Departure Bay, B.C., near 49° 12' N latitude; 123° 58' W longitude. Work was carried out from the 9 m aluminum herring skiff MEGALOPS, equipped with a depth sounder and hydraulic pot hauler powered by a small gas engine. Field work was carried out from August 11 through the end of November 1983.

Traps used were cylindrical ('inside waters' type) traps manufactured for the commercial crab fishery from 16 mm stainless steel rod. Traps were 91 cm diameter, 30 cm high, and covered with stainless steel wire (type 316) to form 50 mm mesh. Two entry tunnels terminated in rectangular openings 10 x 20 cm. Gravity-operated wire 'triggers', with a 100 mm gap, prevented the exit of crabs greater than 100 mm carapace length. Weight was provided by two mild steel bars 30mm by 30 cm, one fitted with a sacrificial zinc anode. Each trap was fitted with a circular escape port of 100 mm diameter, located high on the trap side. Three versions of this trap were used. 'Commercial' type traps were as described, with the escape port open. 'Research' traps were identical but with the escape port covered over with wire mesh to prevent escape of small crabs. 'Modified research' traps were the same as 'research' traps but with the entry tunnels reduced in width to 105 mm with vertical stainless steel wires in order to prevent the entry of larger crabs. Traps were individually numbered with plastic discs.

Initial surveys used single trap sets to determine where crabs could be caught in the Bay. After this phase, traps were set on 'longline' gear, using a 200 m long groundline of 50 mm polypropylene line anchored and buoyed at each end. Ten or twelve traps (depending on the phase of the study) were attached at regular intervals to this groundline with halibut 'snap-on' hooks fastened to the trap with a short gangion. Traps were set along depth contours, normally at depths ranging from 5-15 m.

All Cancer magister caught were measured across the carapace 'notch to notch', from a point just anterior to the lateral spines; measurements were made to the nearest mm rounding down. Shell hardness was noted on a standard scale of 1-5 as follows: 1-fully hard; 2-nearly hard; 3-springy; 4-quite soft; 5-soft areas caused by pre-moulting. Sex, the presence of eggs, injuries and missing limbs were also noted. All Dungeness crabs caught were tagged before release, using orange 'spaghetti' tags (Floy Tag Company, Seattle) inserted into the rear carapace along the suture line on the right side. Only the width of red rock crabs (C. productus) was measured.

Statistical tests reported below were all performed with a standard statistical package (BMDP). The level of significance P = 0.05 was used for all tests.

SPECIFIC METHODS AND RESULTS

Shell hardness

Data from all phases of the study were used to estimate the percentage of softshelled crabs caught each week. Crabs in hardness categories 2, 3 and 4 were considered 'softshelled' for the purpose of this analysis (only one crab in hardness condition 4 was seen during the study). Percentages of softshelled for the 14 weeks of the study, with 95% confidence limits, are shown in Figure 1. The percentage of softshelled was greatest at the beginning of the study in August (30-40%), declined to less than 10% in September, then rose again to 10-20% in October and November.

In all, 68 crabs were observed in hardness condition 5 (pre-molt). These were uniformly distributed over the period August-October. Most (57) were females, with sizes similar to those shown in Figure 4.

Bait efficiency

During experimental fishing in the early part of the study, different baits were used to determine the most effective. Baits used were frozen herring suspended on halibut hooks in the centre of the trap; frozen herring placed in perforated plastic bait jars suspended in the centre of the trap; frozen squid placed in bait jars; and canned commercial dog food. In the earliest phases of the study, baits were tested without experimental design, but later paired experiments were set up to compare the effectiveness of specific baits.

In 10 sets of ten traps each, herring was suspended on hooks in half the traps within a string, and placed in bait jars in the other traps. The two baits were uniformly mixed within the strings. Soaks varied from 1-5 days (most were 1 day). Depths varied from 8-40 m (most were 10-15 m). Mean Dungeness crab catches (all sizes and both sexes) per trap-haul were as follows:

	Herring in jars	Herring on open hooks
mean	2.636	1.556
s.d.	2.798	1.690
n	55	54

A one-way ANOVA showed that the difference between mean catches obtained with these two baits was significant; ($F = 5.93$, d.f. = 1); thus jarred herring caught significantly more crabs than hooked herring.

In two sets, squid and herring baits were mixed within sets. One set was at 16 m for 6 days; the other at 10 m for 1 day. Mean Dungeness crab catches per trap-haul were as follows:

	Squid	Herring
mean	6.60	3.40
s.d.	2.37	1.07
n	10	10

A t-test showed that the mean catches were significantly different ($t = 5.40$, d.f. = 9,); thus squid caught more crabs than herring.

An analysis of bait efficency was also performed on unpaired sets conducted early in the study. Soak times varied from 1-5 days for herring bait in jars and 3-6 days for squid bait in jars. Depths ranged from 10-16 m for both baits. Mean catches of Dungeness crabs per trap-haul were as follows:

	Squid	Herring
mean	3.750	1.988
s.d.	2.806	1.547
n	32	80

A one-way ANOVA showed that the difference between catches using herring and squid was significant ($F = 11.26$, d.f.=1).

Two sets were made in the same area using canned commercial dog food (Tri-V) as bait, because of its success as a bait in prawn traps (J. A. Boutillier, pers. comm.). Both soaks were for 1 day. The average total catch was 0.05 Dungeness crabs per trap tie the line up ($n = 19$, s.d. = 0.23). Comparison with the catches reported above shows that this bait was ineffective.

The effect of trap type on catch rates

For this phase of the study, sets comprised either uniform mixtures of research and commercial trap types, or uniform mixtures of commercial, research, and modified research trap types. Squid in jars was used as the bait in all sets; soak times varied from 1-3 days but were mostly 1 day; depths ranged from 5-16 m. Mean catches of Dungeness crabs per trap-haul were as follows:

	Trap type		
	Commercial	Research	Modified research
mean	1.718	1.842	1.552
s.d.	1.523	1.467	1.478
n	124	114	29

A one-way ANOVA showed that differences among mean catch rates were not significant ($F = 2.54$, d.f. = 2).

Mean catch rates of male and female crabs per trap-haul for each trap type were examined separately with one-way ANOVA.

		Trap type		
Crab type		Commercial	Research	Modified research
Females	mean	0.258	0.456	0.621
	s.d.	0.554	0.777	0.903
	n	124	114	29
Males	mean	1.427	1.377	0.931
	s.d.	1.332	1.353	1.033
	n	124	114	29

Catch rates of females were significantly different among the three trap types ($F = 3.99$, d.f. = 2), but there was no difference among the catch rates of males ($F = 0.50$, d.f. = 2). Commercial traps caught the fewest females and modified research traps caught the most. The non-significant trend among the catch rates for males was the reverse.

Effect of trap type on size distribution of the catch

Using carapace widths of all crabs caught in the sets described in the previous section, the size distributions of crabs caught by each trap type were compared. Size distributions are shown in Figures 2-4. For grouped size intervals of 5 mm, the size distributions of the total catch for commercial

and research traps were compared with a chi-squared test. Crabs caught by research traps were significantly smaller than those caught by commercial traps (chi-square = 27.52, df = 10). Modified research traps were not used in statistical comparisons because the data were too sparse to support this analysis. The size distribution of male crabs were compared separately with a chi-squared test. The difference between sizes of male crabs caught in commercial and research traps was not significant (chi-square = 18.01, df = 10). Data were insufficient to allow comparison of size distributions of females.

Tag recoveries

By the end of the study, 1063 crabs had been tagged. Of these, 846 were legal males. Commercial fishermen were asked to remove tags from legal male crabs and retain them; and to ignore tags on female and sublegal male crabs. Although no lottery was in place for this small study, very good cooperation was obtained from local commercial crab fishermen, who returned 318 tags (37.6%) by 31 December 1983. Most tags were returned from traps set in Departure Bay, but some came from the Jack Point area, 6.8 km away.

The total population of males in the Bay was calculated with simple Petersen estimates (Ricker 1975):

$$N = MC/R$$

where M is the number of marked crabs, C the total number of crabs caught, and R the total number of tagged crabs recovered for the specified time period. This procedure was used to estimate the total number of crabs at a number of points during the study. During the study, crabs were being continuously tagged, and some tags were being removed by fishermen. The number of tags at large was determined as:

$$M = 3.919t + 4.626t \exp(-Dt)$$

where t is the number of days from the beginning of the study and D is the instantaneous rate of loss of tags to the commercial fishery (estimated from the total number of tags returned at the end of the study). The first term represents the rate of tagging of sublegal males, and the second represents the rate of tagging of legal males, corrected by the survival from commercial fishing. Using five weeks from which sufficient crabs were caught, time t was taken as the midpoint of the week. Confidence limits were determined by determining confidence limits around R from the Poisson distribution and substituting (Ricker 1975).

Day t	# Marked M	Recovered R	Catch C	Population N	95% Confidence limits for N
57.5	429	5	43	3689	1577 - 11529
70.5	512	6	84	7167	3283 - 19549
77	551	14	89	3503	2087 - 6369
90	628	12	76	3977	2273 - 7698
97	667	11	55	3335	1862 - 6794

Trawling

Trawling was conducted from the herring skiff, using a small otter trawl (Marinovich try-net, 4 m headrope, 30 mm mesh size, 30 x 75 cm) towed for 5 min at 1-2 knots. Altogether, on four occasions 16 net hauls were made, including 9 during the night. During these hauls, three Cancer productus were caught, but only one C. magister. In addition to these hauls, some trawling was carried out in very shallow water at various speeds with SCUBA divers examining the action of the net. The purpose of the SCUBA observations was to discover whether the net was fishing properly, in light of the previous poor catches of crabs. The net appeared to be fishing satisfactorily. Since an identical net was used successfully earlier in the year to catch Cancer spp. in Fulford Harbour (Richards, unpubl. data), it was concluded that crab densities were very low in the area being trawled, and this part of the study was abandoned.

Trap loading experiments

In this phase of the study, two trap types - commercial and research traps - were used in uniformly mixed sets in three treatments. 'Legal-loaded' traps were pre-loaded with three legal-sized male crabs (155-180 mm carapace width). 'Sublegal-loaded' traps were pre-loaded with four or five sublegal male crabs (130-155 mm carapace width) (the number was consistently four or five within a set and depended on supply). Control traps were not pre-loaded. All crabs pre-loaded were tagged and the numbers recorded by trap so that escapes from traps and newly caught crabs could be identified. Six sets were baited with squid in jars and soaked for one day in 5-15 m. Total escapement of crabs pre-loaded in the traps was as follows.

	Crab type		
Trap type	Legal	Sublegal	Total
Research	0	11	11
Commercial	1	13	14
Total	1	24	25

Legal males escaped rarely from either type of trap, while sublegal males escaped from both types of traps at equal rates of about 30% per day.

The effect of pre-loading on mean catch rate per trap-haul is shown in following table (catch rates exclude pre-loaded crabs).

Trap type		Trap loading		
		Control	Legal	Sublegal
Research	mean	2.143	.917	.818
	s.d.	1.703	1.165	.982
	n	14	12	11
Commercial	mean	.786	.500	.909
	s.d.	.579	.798	1.136
	n	14	12	11

ANOVA	Sum of squares	df	Mean square	F value	Tail probablity
Trap type	5.7641	1	5.7641	4.53	0.0369*
loading	8.3648	2	4.1824	3.29	0.0434*
interaction	6.8313	2	3.4157	2.68	0.0755

*Significant CP ($P < 0.05$).

The two-way ANOVA showed the two trap types caught crabs at significantly different rates; research traps being more effective. Pre-loading caused significantly lowered catch rates. Legal and sublegal loadings appeared to be roughly equal in effect, and commercial traps were much less affected by loading than research traps. Interaction effects were present but not significant.

DISCUSSION

Size selectivity of different gears

The main objective of this study, which was to develop selection curves for several types of gear, could not be met. Traps could not be compared with trawl results because trawling was not successful in catching crabs. Significant size differences were seen in crabs caught by research and commercial traps, but too few individuals were caught to permit construction of selection curves.

The failure of trawling to catch crabs was probably caused by a scarcity of crabs smaller than 115 mm width. Trawls are selective for smaller crabs, since larger individuals are able to outrun the net (Gotshall 1978). Thus the absence of small crabs in the trawl hauls probably reflects their absence in the area trawled. If small crabs are not present in this area, this would also explain why research traps did not catch smaller males than commercial traps, as might have been expected. Crabs larger than 115 mm were obviously present, since they were caught in the traps, but their low density is indicated by the relatively low trap catch rate (approx. 2 crabs per trap

haul). It not likely that the trawl was to blame, since diving observations showed the net to be fishing properly, and a similar net had been used successfully elsewhere.

The apparent difference in size selectivity between commercial and research traps was related to both a non-significant difference in the sizes of males caught and to the increased catch of females in research traps. Differences among trap types in their catch rates can be explained as saturation effects. Miller (1979) suggests that crabs interact behaviorally such that each crab in a trap decreases the probability of further entry, until a saturation is reached at which either no more crabs enter or the rates of entry and escape are equal. Based on this, he recommends that catches of legal sized crabs can be increased by allowing sublegals to escape at a high rate. The trend in catches of males tends to support this view: commercial traps caught more males than research traps. Modified research traps, because they prevented entry of legal crabs, caught the fewest males.

The trend for female catch rates was the reverse, and was significant. This can also be explained as a saturation effect. Modified research traps kept larger crabs (i.e. males) out, and as a result these traps caught more females than research traps. Commercial traps caught the fewest females because females were able to escape. Thus for catching females, a trap should be designed both to exclude crabs larger than the largest females and to prevent escape of small crabs.

The trap loading experiments tested the effects of saturation at low densities. In Boundary Bay, where some traps are still set without bait, the practice among fishermen is to place one crab in the trap. This would suggest that at least the first crab to enter a trap increases the probability of further entry, which is a view opposed to that of Miller (1979). Since the traps used in this study appear to be capable of retaining at least 30 crabs per trap (based on observations of the commercial fishery), traps were loaded with three legal males or 4-5 sublegal males as 'low-density' loadings. Even these levels caused significantly reduced catches, which supports the view of Miller (1979). Commercial traps, with a lower base catch rate, were less affected by loading than research traps, and were least affected by sublegal loading (since sublegals could escape). Total catch rates in research traps were halved by these levels of loading. Legal and sublegal loadings appeared to create roughly the same effect.

Trap loading studies also provide some evidence concerning the abilities of crabs to escape from traps, at least over a short time. Legal males generally did not escape. High (1976) also observed that triggers were effective in preventing escape of legal sized crabs. Sublegal males escaped about equally from both traps with and without escape rings - presumably leaving through the entry tunnels between the triggers.

The bait efficiency comparisons showed that hanging herring was less attractive than herring in jars. Miller suggests (1979) that bait performs two functions: it attracts crabs towards and into a trap, and it provides incentive for them to stay inside a trap rather than escaping (when escape is possible). Thus he suggests that a bait which is available to the crabs (hanging bait) should be more effective than bait in jars which is simply acting as a source of odour. That our results were the reverse with herring

suggests a third process - crabs in a trap attack the bait and gradually reduce its effectiveness. Whether hanging bait is more effective than jarred bait probably depends on the mechanical properties of the bait used and the ability of crabs to exercise an option to leave the trap, as well as on saturation considerations.

Numbers of male crabs in Departure Bay, estimated from the ratio of marked and unmarked crabs caught over the course of the study, appear to be 3000-4000. Although each week's estimate had very wide confidence intervals, successive weeks provided very similar estimates with one exception. This indicates that such estimates might be successful with marking frequencies as low as those in this study. These estimates depend, however, on two assumptions. First, it must be assumed that there is no natural mortality. This was done since nothing is known about natural mortality rates in this population, but is unlikely to be true. A second assumption is that no migration to or from the study area takes place. This assumption is violated, since crabs were recaptured as far as 7 km away. Tag return rate was too low to permit estimation of migration rates in these crabs, but significant exchange between Departure Bay and surrounding areas is indicated. This is also suggested by the absence of small crabs in the study area.

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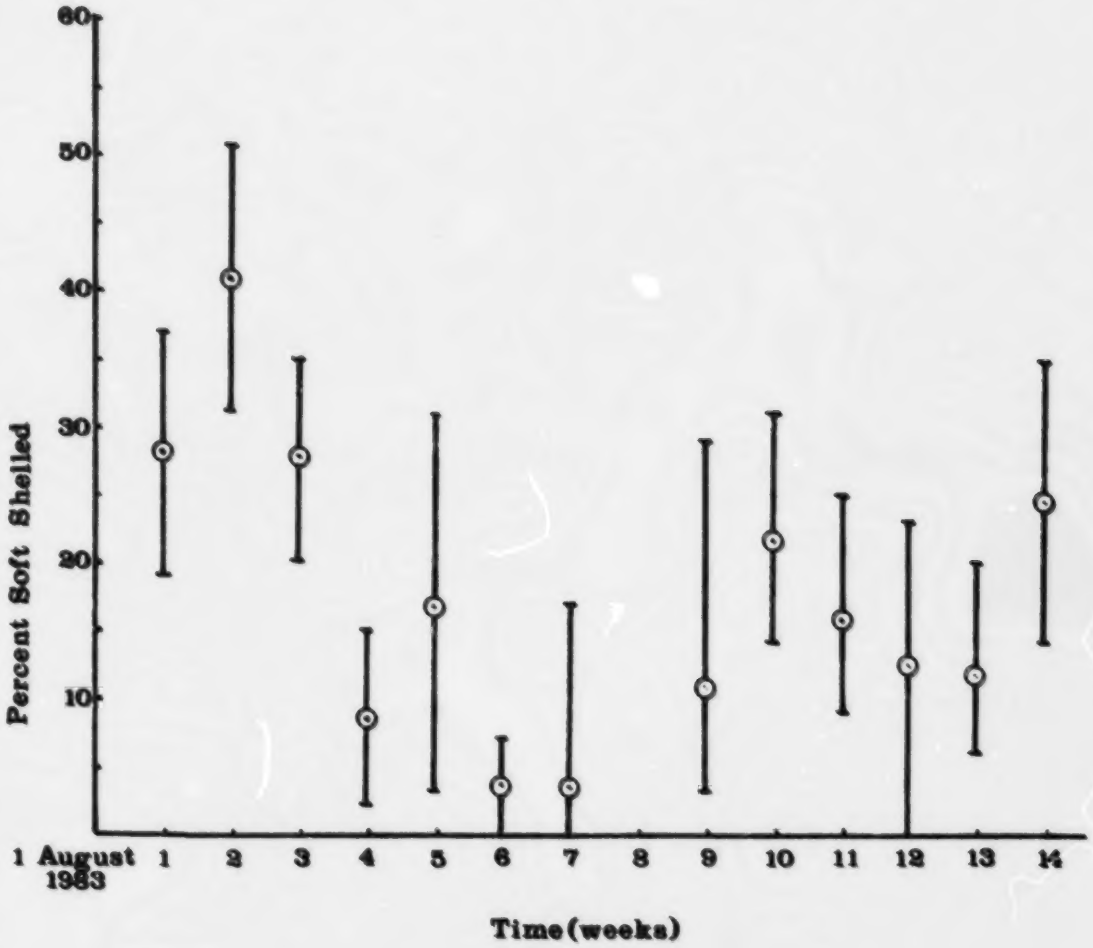


Fig. 1. Percentage of soft-shelled crabs (subjective hardness index 2-4) over the course of this study.

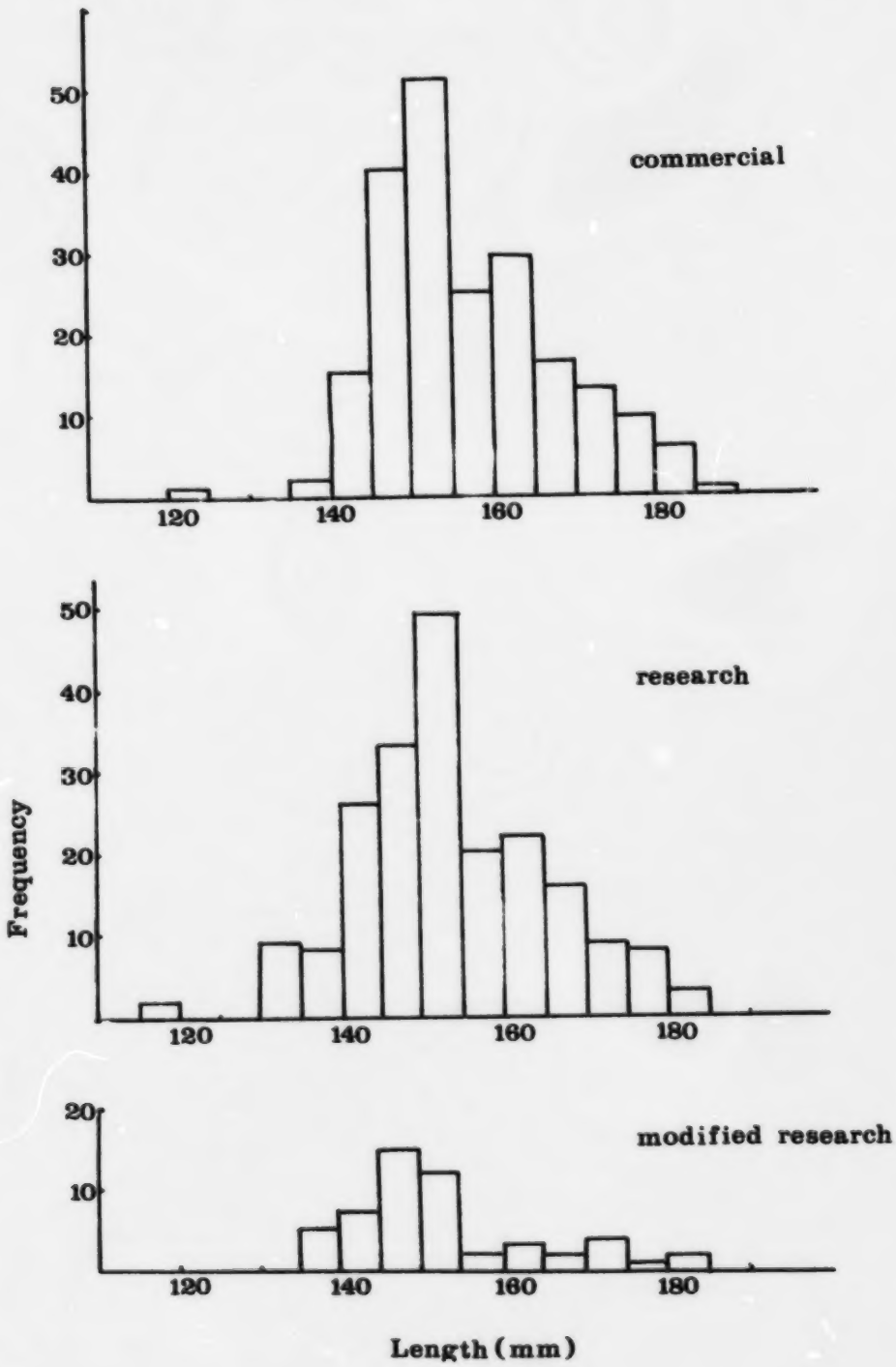
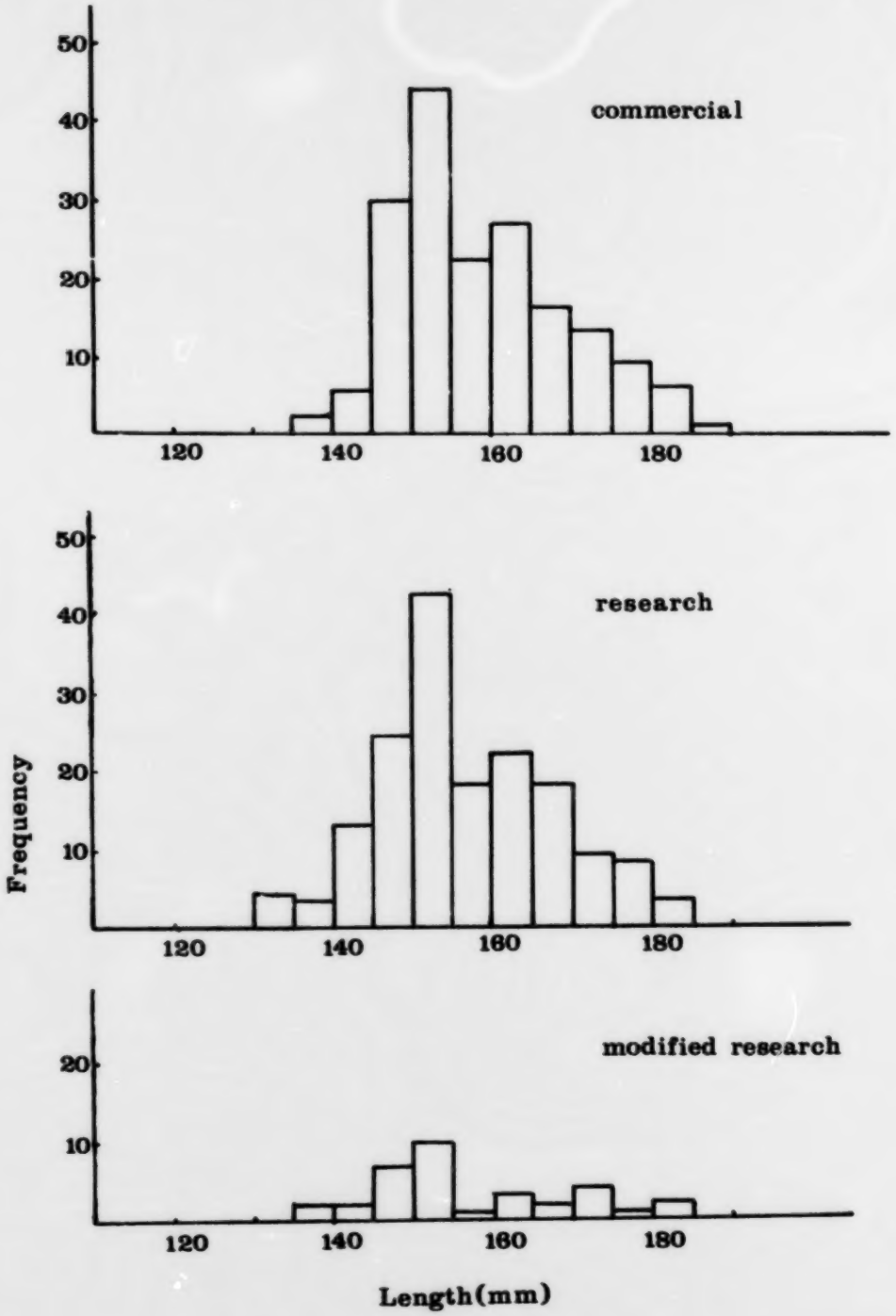


Fig. 2. Width frequency of total crab catch by the three trap types.



Ftg. 3. Width frequency of males caught by the three trap types.

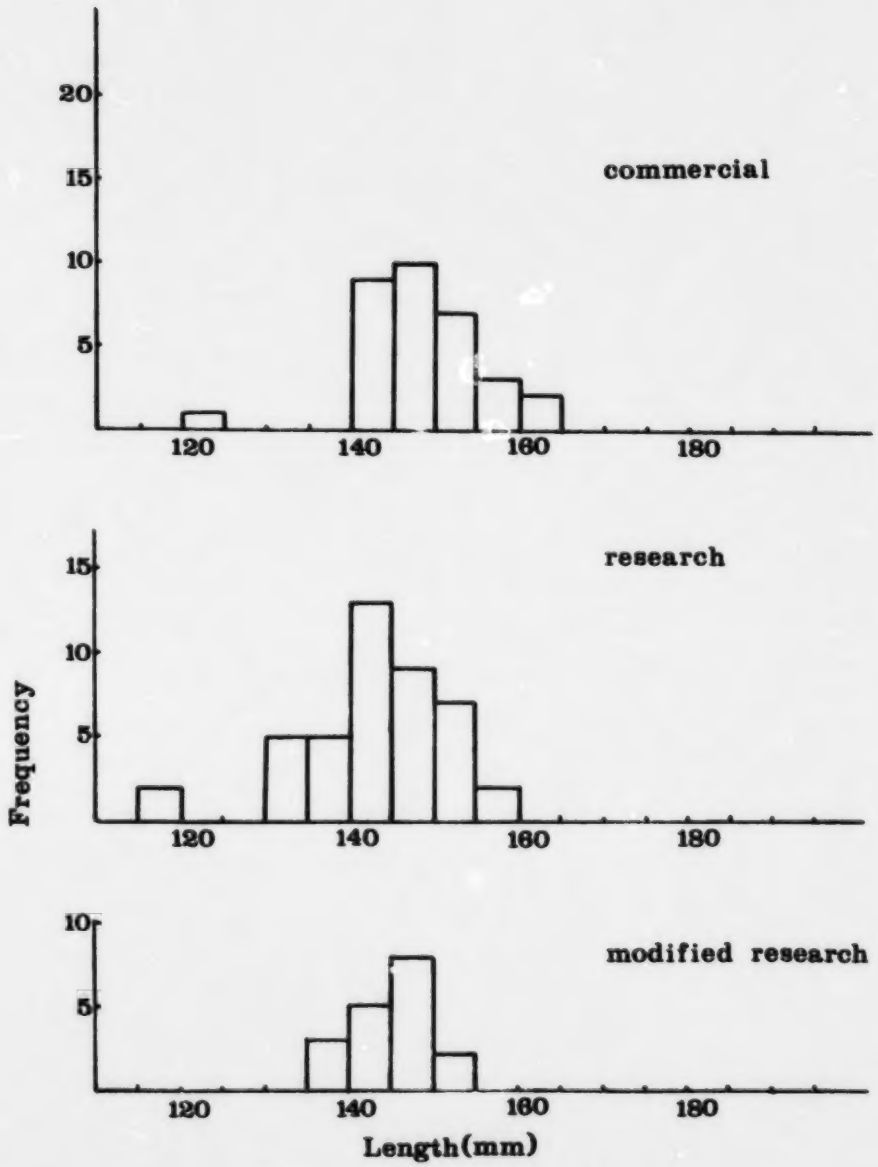


Fig. 4. Width frequency of females caught by the three trap types.

PRELIMINARY ANALYSIS OF FRASER DELTA TAGGED CRAB RETURNS, MAY - NOVEMBER 1984

by

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ABSTRACT

Movement of tagged crabs off the Fraser River delta was examined to determine whether male crabs show directional movement during and subsequent to the annual softshell fishery closure in May, June and July. The study was conducted in response to complaints by fishermen that the softshell closure allowed crabs to become unavailable to the fishery. In May and June 1984, 2256 male crabs were tagged and released on Roberts and Sturgeon Banks. Letters and tag recovery forms were distributed to the fishing industry and related persons. By late November, 465 tags had been observed or returned, of which 211 provided information useful to this analysis. Crabs tagged in both May and June moved an average of 0.9-1.3 km per day, but movements showed no pattern of directionality. Possible improvements to a study of this type are discussed.

INTRODUCTION

This study is a preliminary analysis of movements in male Dungeness crabs (Cancer magister) tagged in May and June on Roberts and Sturgeon Banks on the Fraser River delta. The purpose of the study was to determine whether directional movements occurred in male crabs, especially during the May-July period when the fishery was closed to protect soft-shelled crabs. Fishermen had suggested that crabs moved out of fished areas during the annual closure.

Little is known about migration of crabs in this area. One study examined movements of crabs in an area of dredging on Roberts Bank (Archibald & Bocking, unpubl. data). The number of crabs followed with sonic tags in that study was too small to show a clear pattern. It is probable that inshore/offshore movements associated with mating occur, as such movements are widely documented in other Dungeness crab populations (see Diamond 1983 for review). Along shore movements, however, are not well documented and show little consistent pattern among geographical areas. Gotshall (1978) suggests that movements in California are related to prevailing currents along the California coast. Butler (1951) and G. D. Heritage (unpubl. data) have found

significant movements parallel to shore in male Dungeness crabs in Dixon Entrance and Hecate Strait.

Strongly directional movement patterns, if discovered, would have management implications. If males indeed migrate during the closure period away from areas where they are available to the fishery, then the overall impact of the closure might have to be re-evaluated.

Although this concern may be highest in the Boundary Bay area, where crabs can easily move across the International Boundary, this study was restricted to Roberts and Sturgeon Banks. A study conducted in Boundary Bay would require tagging on both sides of the boundary, and hence would require a co-operative project with American biologists. Such a program was not feasible in the time available for the study described here, but might be practical in the future.

METHODS

Crabs were caught and tagged from the research vessels CALIGUS and ACTIVE LASS on two trips: 15-18 May and 19-22 June 1984. Forty-five traps were used, divided into three groups of 15 traps each and set at depths of 10, 30 and 70 m at stations near the Canoe Pass light and Sand Head light. Within each group of traps, five traps each of three trap types were used. The basic type was a cylindrical trap, 91 cm diameter and 30 cm in height, manufactured for the commercial fishery from 16 mm stainless steel rod. The frame was covered with type 316 stainless steel wire to form a 50 mm mesh. Two entry tunnels, with rectangular openings 10 x 20 cm, entered the trap from opposite sides, and were fitted with 'triggers' to prevent the escape of crabs greater than approximately 100 mm carapace length. Weights was provided by four 30 mm mild steel bars 30 cm long (extra weights had been fitted for a previous study). Sacrifical zinc anodes were provided. One variation of this basic trap was fitted with a circular escape port 100 mm in diameter, located high on the trap side. A second variation had no such escape port. The third variation was double-wired to reduce the effective mesh size by half, had no escape port, and was fitted with extra triggers to prevent the escape of crabs through the tunnel.

Previously frozen whole squid was used as bait. All soak times were 24 h. Crabs caught were all measured, sexed, examined for shell hardness, mating marks, missing limbs and injuries. All males larger than 152 mm carapace width (measured between notches) were tagged with blue plastic 'spaghetti' tags (Floy Tag Company, Seattle) inserted into the right rear carapace along the suture line. Crabs were returned to the water within 10 min of capture in all cases.

In all, 2256 tags were released on the two trips. In May, 849 were all released at the point shown on Figure 3, and in June 1407 tags were released at the point shown on Figure 4.

For the purpose of recording returns, the study area was divided into numbered areas on a grid pattern (Fig. 1). Grid rectangles are 1 min of latitude by 2 min of longitude (1.85 x 2.42 km at this latitude), and are consecutively numbered within the Departmental statistical area and sub-area system. Rectangles were limited to the area in which crabs were likely to be caught by pot gear, and so extended from the intertidal zone to approx 100 m depth.

Because even researchers are sometimes confused by the region/area/subarea/subsubarea grid system, the system was considered probably too complex for fishermen to use when filling out tag return sheets. Therefore a special map (Fig. 2) was prepared for the use of fishermen. On this map the grid rectanglar areas of interest were simply numbered consecutively.

All fishermen for whom addresses could be found either through District Office records or through searches of the CFV system, were sent a letter explaining the purpose of the study, a waterproof map showing the grid system (Fig. 2), and a couple of waterproof tag recovery forms (Appendix 1). The forms were designed to be filled out with a small amount of effort and were designed so that a coder could enter the actual grid number from the simplified system number provided by the fishermen.

As incentive, a lottery with 5 prizes of $100 was established, to be drawn on March 29, 1985.

Packages containing maps, forms, letters of explanation and posters were also sent to Fishery Officers, the District Office, the DFO information office, and regional biologists. Processing plants were sent similar packages, and informed that plant workers were eligible to enter the tag return lottery. Posters and information packages were also sent to all wharfingers in the area, through the Small Harbours Branch.

Tag returns were all recorded on standard forms and keypunched. Records with tag number and date and place caught were separated into May and June releases. For each tag time at large, distance travelled and direction of travel were calculated. These data were used to estimate circular movement parameters (Batschalet 1981).

RESULTS

Tags were returned by fishermen, other researchers, recreational fishermen, plant workers, marina operators, and retail crab buyers. Two tags were returned from crabs bought in retail stores in Alberta and California. However, commercial fishermen accounted for a very high percentage of tags returned. To 19 November 1984, 465 tags had been returned or observed. Of these, 211 records contained enough information to be useful in the analysis.

Movement statistics from tag returns are shown in Table 1. Crabs moved both north and south from tagging sites, at a mean individual rate of

0.09-0.13 km per day, ignoring direction. This figure is consistent with estimates from crabs tagged in Hecate Strait (T. H. Butler, unpubl. data; G. D. Heritage, unpubl. data). However, movements from both May and June releases appear to be equally divided between northward and southward, thus, the rate of group movement was low. Crabs tagged in May tended to show a slight northward movement, and those in June a slight southeastward movement; but these trends were not significant (Table 1).

DISCUSSION

These results tabulated to 19 November 1984, must be taken as preliminary, because more recovered tags may be forwarded to the Department. Letters are being sent to commercial crab fishermen to call in outstanding tags.

The number of tags returned to date was lower than one might have expected from the probably high rate of fishing mortality. Roughly 10% of the males tagged provided as useable return records (either from returned tags or from our own observations). Of about 100 fishermen in the local crab fleet, only 14 vessels returned tags. Many of those were vessels with whom we had direct personal contact (observers used these vessels, or some form of contact was made with these vessels while they were fishing). This suggests that a higher rate of return might have resulted from greater personal contact with the fleet.

Some fishermen complained that the form was too complex. Most of those who completed tag return forms did so remarkably thoroughly and appeared to experience no problems. In these cases, the grid system worked well. During follow-up, an attempt will be made to determine whether complexity of the form had an impact on returns. A second complaint was that fishermen found it difficult to record the area, which involved reading and recording the tag while in the process of hauling traps from a variety of locations. Some of the incomplete returns suffered from having no area listed. Further tagging and return work should try to address this problem.

A potential problem with this type of study is that the location of release can be controlled, but the location of fishing gear which recovers tagged crabs cannot be. If a release point were different from the centre of non-randomly distributed fishing gear, then because recoveries are directionally distributed apparent movement trends could be observed when none really existed. Such an effect probably does not exist in this study. There are two lines of argument for this statement. First, although the precise distribution of gear can be determined only with a logbook survey, it appears that gear is heavily distributed over most of the edge of the Banks within the study area. Further, it appears that competition for fishing space results in a more even gear distribution than would otherwise be the case. Second, since no significant directionality was observed, any significant artifacts of non-random gear distribution would have to be such as to cancel a real directional movement. Because tags were released at two different locations and the results were the same, this is unlikely.

Additional analyses will be reported in 1985.

ACKNOWLEDGMENTS

I wish to thank all the following people for their help. Wayne Harling organized the tagging program during May and set up the grid system. He was ably assisted by Brenda Nicoll, Judith Thomson and Luigi Martinelli. Sandy Mathieson skippered the ACTIVE LASS, and the crew of the CALIGUS assisted during the first trip. Brenda Nicoll was invaluable in setting up the tag recovery system. Marc Hamer provided me with a Julian-date subroutine for the analysis, and Steve Head assisted with data manipulations and provided drafting assistance for this publication. I especially wish to thank those fishermen who co-operated with the program in providing usable data, and with the staff of the Steveston Fishery Office for their help.

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Table 1. Movement statistics from tag recoveries. NS=not significant.

Month	May	June
Number of returns	87	124
Mean individual velocity (km per day)	0.09	0.13
Mean angle of heading (degrees true)	45.84	159.0
Group velocity (km per day)	0.02	0.04
Mean square dispersion	0.30	0.42
Rayleigh Statistic R	8.824	11.853
z	0.856 NS	1.115 NS

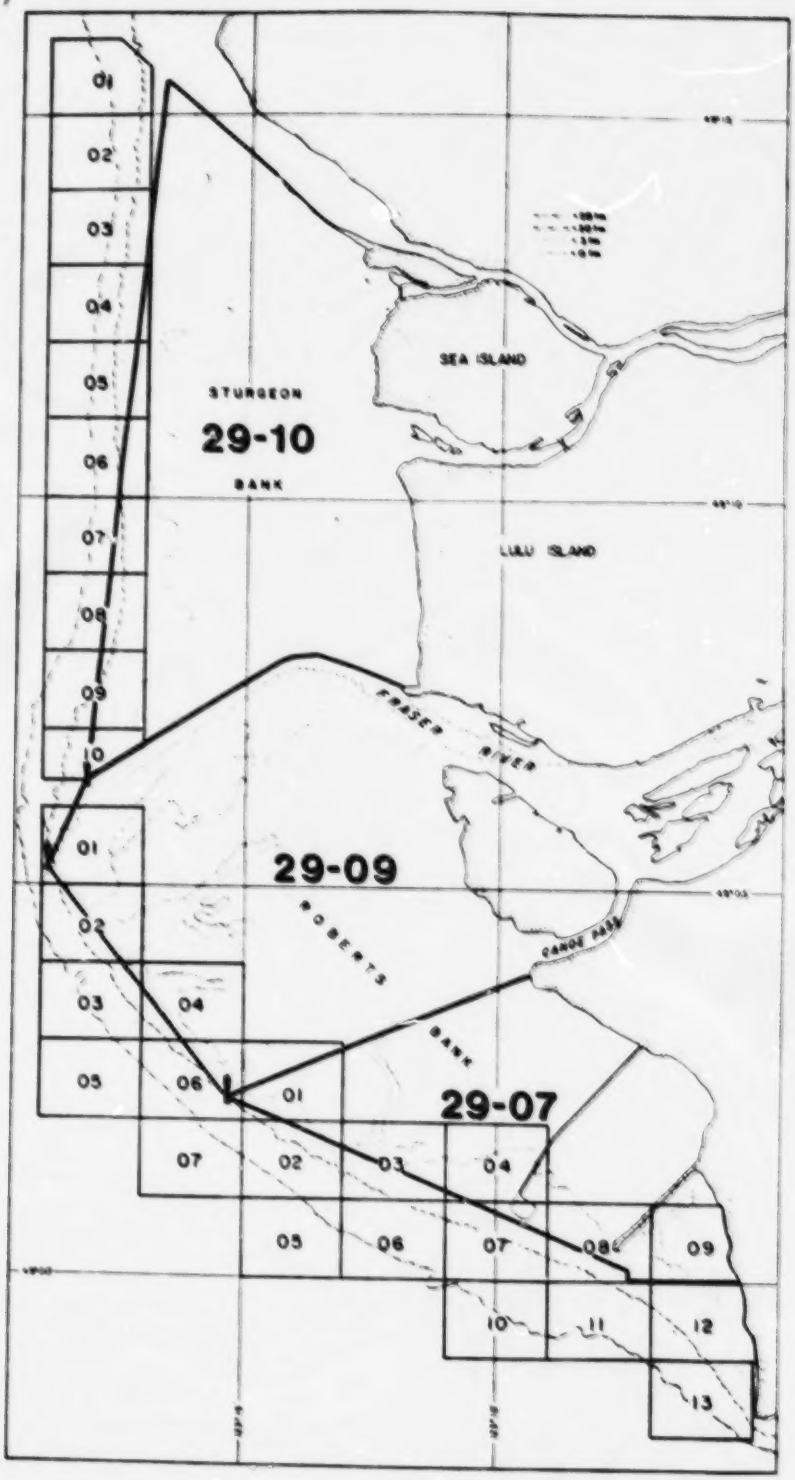

Fig. 1. The grid system used by this study. The three major areas in boldface are statistical subareas of Area 29, established by Field Services Branch. The numbered sub-subareas were established by this study.

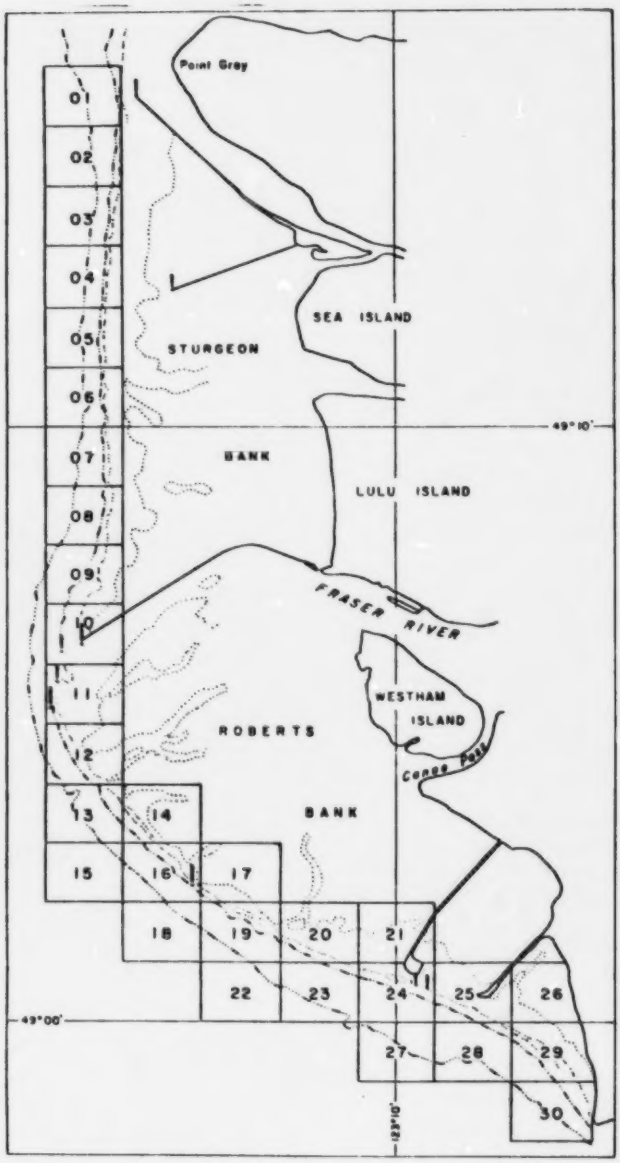

Fig. 2. The simplified grad system supplied to fishermen. Tag return information was recorded on arrival to conform with Figure 1.

GHOST FISHING BY DUNGENESS CRAB TRAPS: A PRELIMINARY REPORT

by

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ABSTRACT

This is a preliminary report of a study to determine whether lost crab traps continue to catch and kill crabs (Cancer magister). Direct underwater observations of lost crab traps suggest that traps retain the capacity to fish for a considerable time, and that they do catch crabs as long as they are able. Direct observations of simulated lost traps shows that lost traps continue to fish, but at a lower rate than freshly baited traps, for at least several weeks from the simulated loss. These studies, show that deaths within traps, and continuous entrance and escape make the actual fishing rate difficult to determine except by closely-spaced underwater observations.

INTRODUCTION

A considerable number of Dungeness crab (Cancer magister) traps are lost every year, for a variety of reasons. Fishermen try hard to avoid losses, because traps are expensive, but they occur anyway. Traps are fitted with 'triggers' which allow legal-sized crabs to enter the trap but prevent their escape. Because escape ports are too small to allow legal-sized crabs to pass through them, legal sized crabs cannot escape from a properly functioning trap (High 1976). Thus a lost trap with properly functioning triggers which has attracted legal-sized crabs before the bait is consumed or decays will kill most of those crabs. Escape ports, which in British Columbia are required to be 100 mm in diameter, allow most sub-legal crabs to escape.

If lost traps killed only those legal crabs attracted to the baited trap, the number of crabs killed by lost traps would be small. However, "ghost fishing", a phenomenon in which crabs within a trap attract other crabs, may occur. They might do this either because of their occupation of the trap (some positive social effect) or because they die and their bodies 're-bait' the trap. In the only other study of Dungeness crab trap loss, High (1976) did not look at this phenomenon. Pecci et al. (1978) suggest that lost lobster (Homarus americanus) traps continue to fish for at least several months, and that they kill twenty-five percent of the animals they catch.

In Alaska, all traps placed in the sea are required to have a panel which will open after the destruction of degradable fibre. In British Columbia, however, no regulation of this kind exists. Experiments previously made (T. H. Butler, pers. comm.) with electrolytically degradable trap components were not successful. Local variations in temperature and salinity made the lifespan of components difficult to predict, with unsatisfactory results to commercial fishermen.

In the absence of experimental evidence concerning this problem, opinions vary. Some fishermen suggest that traps cease to attract crabs after the bait has gone, and they support this suggestion by saying that crabs found in traps recovered after a very long soak are dark and hard (i.e. they have not moulted, and have been in the trap for a long time). Against this, however, traps are sometimes set unbaited in Boundary Bay. As these traps catch crabs it seems probable that lost traps at least in that area may do so also. Another suggestion is that rubber lasts only a short time on a lost trap. According to this view the cover latch (usually constructed from inner tube rubber) breaks, allowing crabs to escape; and the frame wrapping deteriorates, allowing the frame to corrode. A related view is that continuously submerged traps lose the sacrificial zinc annodes in a short time, after which the wire mesh degrades quickly. Yet another view is that traps set in the Fraser river delta are buried in silt (by direct accretion and by gradual sinking) in a short time and thus cease to fish.

The overall study was designed in several parts. The object was to determine whether ghost fishing is a problem serious enough to warrant attention. The first question asked was whether or not lost traps catch and kill crabs. If they do, the next questions are the rate at which they fish, how long they continue to fish after loss, and how many are lost to fish in this way. The procedures and results presented here address only whether lost traps catch and kill crabs.

METHODS

Boundary Bay observations

Field observations of lost traps were made in Boundary Bay on 28 August 1984. In Boundary Bay, traps are set as close to the International Boundary as possible and form a dense band within which trap density appears to be about one per 1000 m^2. Two divers at that time had contracted with a fisherman to try to recover a large quantity of gear that he had lost. Their procedure was to search circles of the bottom defined by the radius of a tag line running from the boat to the diver. My observations were made in company with the diver searching these circles.

Departure Bay observations

In Departure Bay, ten stainless commercial-style traps (see Breen, p. , in this publication) for a description of these traps) were set to simulate lost traps. The traps, baited with squid in bait jars, were set in 13-16 m depth on 15 October 1984. Traps were set with 'snap-on' hooks to a common groundline with light concrete anchors attached at each end. On 29 October, the traps were observed by diving. Because of problems with depth

and the way the string had been set, the string was pulled, all crabs were measured, tagged and replaced, and then the string was re-set in a better location. One trap had lost its bait jar, and was left unbaited.

Diving observations were made on the 5th, 14th and 19th November, 1984. At each visit, the numbers of previously tagged crabs, dead crabs and lost tags were noted and new trap occupants were tagged. During each visit, the bait was left undisturbed. The behaviour of trapped crabs and the physical situation of each trap was noted.

RESULTS

Boundary Bay observations

In the course of one afternoon, about 2100 m^2 of sea floor was searched. Visibility was generally poor (2-5 m), but the area estimated was searched quite thoroughly. Within that area, several traps being fished were seen (traps either bouyed at the surface or attached to a clean longline). Two lost traps were found, and are described below. Lost traps were easily identified by their appearance. Four ruined traps were found (traps which had been damaged to the point that they no longer retained a capacity to fish).

Of the lost traps, one appeared to have been lost within a few weeks to two months. This estimate was based on traces of rotten bait still contained within the bait jar and barnacles on the frame (indicating a loss time of at least a few weeks). This trap was not silted. The trap contained nine crabs (8 males, 1 female), ranging from 148 - 185 mm carapace width (measured notch to notch).

The second trap had been lost for considerably longer, as it had become silted in to a level halfway up the entrance tunnels. The trap frame was covered with barnacles (Balanus crenatus) and algae (Gigartina sp., Laminaria saccharina, Desmarestia ligulata, var. ligulata and unidentified small reds). The buoy line appeared to have been cut by a propellor. The triggers were silted in, and this trap may no longer have had the ability to catch crabs. Nevertheless, it contained four live crabs, ranging from 141 - 155 mm carapce width. The one female was heavily encrusted with barnacles. When the trap was broken out and taken to the surface, it was discovered to be essentially intact. No part had suffered visibly from electrolysis, and the rubber latch was in good condition.

Departure Bay observations

When the simulated lost string was returned to the water on 29 October, the traps contained 34 Cancer magister and one C. productus in eight traps (two traps were empty). The unbaited trap, empty on 29 October, and another trap empty on that date have remained empty. On 19 November, the traps contained 40 C. magister plus one C. productus. The minimum number of deaths observed was four. Twenty-five new entrants had been tagged, and at

least 15 tagged crabs had escaped between observations. Thus, over 21 days, the net number of crabs caught increased by six overall, but this figure increases to 10 when deaths are included; and the figures show a large turnover rate within the traps. These observations continue.

The traps remain in good condition. The floors are just beginning to become covered with silt, and as yet there is no evidence of impaired function. The crabs are still active when disturbed. During the first week of observations, crabs burst into activity when divers approached the trap. After one week, many crabs remained immobile on the trap floor unless the trap was opened. Several times, new entrants have, upon being replaced in the trap after tagging, travelled directly to the escape port and tried to escape.

DISCUSSION

The observations presented above show that crab traps do continue to catch and kill crabs after having been lost. The Departure Bay observations indicate that the rate of fishing by lost traps is slow compared with that of freshly baited traps, supporting Pecci et al. (1978). They also indicate that because of deaths taking place within the traps and continuous turnover of crabs inside the traps, the number of crabs found in a trap is not a reliable indicator of the fishing rate of the trap.

Observations in Boundary Bay confirm that traps may continue to fish for a relatively long time. One lost trap had apparently been submerged for at least a year yet was in good condition, and only extensive silting appeared likely to stop it from fishing. The deteriorating rubber theory was disproven. How fast a trap deteriorates from electrolysis must depend on many number of factors, not all of which are easily manipulated. However, at least some traps continue to fish for more than a year. The observed density of lost and ruined traps suggests a significant trap loss rate.

The next steps in this study, apart from continuing to measure the rate of ghost fishing, will be to conduct a questionnaire survey of trap loss. Traps are lost for several reasons. Bouyed traps may be lost when the buoy lines are cut by vessel traffic. Buoylines may be cut intentionally in the course of 'gear wars' (when crab fishermen compete for a desirable location), or when crab buoys interfere with salmon gillnets. Gear set on unbouyed longlines may be lost if the location has not been properly determined at the time of setting, or if the groundline becomes too deeply buried. Because fishermen complain of gear thefts, it is not possible to separate theft loss from true loss. However, a survey should determine the maximum and miniumum loss rates. From this information, the possible impact on the fishery can be determined.

ACKNOWLEDGMENTS

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FEASIBILITY OF IMPROVING GEODUCK STOCK ASSESSMENT: HISTORY OF THE PROBLEM, RECOMMENDED METHODS AND THEIR COSTS

by

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ABSTRACT

The history, methods, and problems with geoduck, Panope abrupta, stock assessments in British Columbia and Washington State are recounted. Methods are diving surveys in shallow water and remote sensing in deep (>18.5 m) water. Objectives for improving stock estimates in British Columbia are discussed and a shallow water diving system using a belt transect (2 x 25 m or 2 x 50 m) as the sampling unit is recommended. Costs are estimated for the system and compared with those incurred by Washington State workers in the management of their fishery. Because of its expense and relatively low accuracy, remote sensing is recommended for qualitative exploration of new areas only.

INTRODUCTION

The first six years of British Columbia's geoduck (Panope abrupta) fishery (1976-1981) have been reviewed by Harbo and Peacock (1983). From shallow waters (<18.5 m) they estimated stocks of approximately 115,000 t along the coast south of 51°N (Fisheries Statistical Areas 11 to 27) which itself includes areas as yet unsurveyed. Stock estimates have developed into an important management problem for they are the contentious base upon which catch quotas are set. Known beds cover approximately 10,000 ha of which 93.8% have been reported from the south coast. This disparity will change if a proposed processing facility in Port Hardy becomes active, making it logistically more feasible to handle product from Statistical Areas 6 to 11. North Coast Statistical Areas 1 to 5 remain poorly known and underutilized.

The present situation of poor knowledge of stocks hinders expansion of the fishery and fosters scepticism of the industry in quotas determined by management (R. M. Harbo pers. comm.). I report on the history of geoduck stock estimates and discuss feasibility and cost options of improved stock estimates.

PREVIOUS GEODUCK STOCK ASSESSMENTS

British Columbia

The only published report on abundance and distribution of geoducks on a large scale in British Columbia is that of Cox and Charman's (1979) survey in Statistical Areas 12 to 18 between Vancouver Island and the mainland coast. From charts they arbitrarily chose sites which appeared to have "suitable unconsolidated material" between 0-18.5 m depth. Not all such areas were surveyed though. Beds to be surveyed were estimated for size planimetrically from charts. Transects 2 m wide x 50 m long and, where possible, perpendicular to shore were selected for each bed. There was no fixed distance between transects so the number of transects per bed was determined by site-specific and manpower constraints. Between June to November, 1977 teams of divers surveyed each belt transect along adjacent one meter bands. Only geoducks 'showing' siphons were counted. Geoduck densities were estimated by pooling transect counts and dividing by the number of square meters surveyed. The bed estimate was then calculated by multiplying the geoduck density by the number of hectares estimated planimetrically. For each Statistical Area all such bed counts were pooled for abundance estimates. The biomass of geoducks in a subsample of beds was estimated by calculating the mean drained weight of whole clams and multiplying by the number of clams and hectares of beds in that Statistical Area. In beds where no geoduck weights were measured an arbitrary mean individual weight of 800 g was selected from the lower end of the range of geoduck weights reported from commercial landings.

The authors suggested a 'clumped distribution' within beds but provided no statistical evidence. Statistical Areas 12 to 18 were estimated to contain approximately 18.8 million geoducks representing ≈20,100 t. Some factors infuencing accuracy were:

(a) Probable 'beds' were chosen and their areas calculated without reference to the field.

(b) Not all probable beds were surveyed.

(c) Sampling intensity of beds was not uniform.

(d) Although field work occurred mostly over the warm season (June to November) no 'show factor' correction (Goodwin 1977) was applied to the transect counts.

(e) Estimates of mean geoduck biomass were not calculated from systematically gathered individuals.

Cox completed a second survey, as yet unpublished, on abundance and distribution of geoducks off the west coast of Vancouver Island (Areas 23, 24, 25) and some North coast areas. Harbo and Peacock (1983) cite Cox's unpublished data and analyses of log book returns to supply estimates for Statistical Areas 11 and 19 to 27. Added to Areas 12 to 18, the total estimated biomass was 115,200 t (Harbo and Peacock 1983). In British Columbia nothing is known about geoduck resources from depths >18.5 m.

Washington State

Stock surveys began in 1967 and continue to be the responsibility of the Department of Fisheries. Commercial harvesting started in 1970 and is managed by annual public auctions of geoduck bed leases. The fishery now occurs in waters >5.5 m (18 ft) below zero tide line and >182.9 m (200 yd) seaward of the mean high tide line. The fishery is run in cooperation between the Departments of Fisheries (DF) and Natural Resources (DNR) (L. Goodwin pers. comm.). Lease site selection, lease boundary demarcation and buoying is completed by DNR. DF then estimates geoduck numbers, quality, substrate type and depth in the lease tracts. DNR takes these data, plus lease size and exposure to weather conditions, and estimates a reserve bid price for each lease based upon a price per pound of clams. All business aspects of contracts, bidding and lease appropriation are handled by DNR.

Goodwin (1973) reviewed the assessment methods and early history of the fishery. It is now known that 100% of the population can be 'showing' at any one time in the warm months and down to 0.0% be 'showing' in the cold months (L. Goodwin, pers. comm.). Goodwin's survey data of 51 sites in 1983 and 1984 during the prime 'show' factor time (April-June) yielded an average 'show' factor of 66% (range 43 to 100%). Stock assessments were done using standard 1.8 x 45.7 m (2 x 50 yd) belt transects perpendicular to shore in waters <18.3 m (~60 ft) deep. By 1973 over 1100 such transect counts had been recorded and over 145 sites had been classed subjectively as to their geoduck abundance. After surveys, areas were planimetrically estimated and their geoduck population estimated according to mean density from transect counts. Approximately 13,324 ha (32,925 acres) yielded an estimate of 64.8 million clams which, when adjusted with a maximum show factor of 60%, yielded a refined estimate of 106.4 million geoducks. 'Good' beds were those having $\geq$ 2.6 geoducks m^{-2} (3.3 $yard^{-2}$). Goodwin (1978) later summarized all transect data bewtween 1967 and March 1977 (adjusted for seasonal 'show' factor). Beds comprised an estimated 13,678 ha (33,799 acres) with a 'show' factor-corrected estimate of 117.6 million geoducks in the Puget Sound region. There are now approximately 5000 belt transect counts in a data base at DF. Fishery management, unlike in British Columbia, utilizes an extensive data base.

(i) Shallow water surveys

Shellfish management biologists complete shallow water (<18.3 m ~60 ft) diving surveys at two levels of accuracy (L. Goodwin pers. comm.):

(a) Exploratory, relatively superficial geoduck surveys carried out according to the availability of funds at that time. Divers swim 1.8 x 45.7 m (2 x 50 yd) transects perpendicular to shore counting all 'shows'. Most of these are done in areas considered likely to have geoducks. Muddy areas in the heads of bays and swift current channels with gravel or rocky substrates are not surveyed (L. Goodwin, pers. comm.). Furthermore, large, north Puget Sound areas (Anacortez, Everett, Bellingham) are also excluded because of their characteristically low stocks. These surveys are opportunistic and of lower priority compared to the detailed surveys described below.

(b) Detailed surveys for commercial leases are requested by DNR. These rigourous surveys require accurate counts as well as grading of adults according to a combination of size and meat colour. Accurate quality and abundance estimation is essential as these leases will be auctioned to the industry. Prior to leasing, bidders can visit and assess leases for themselves to evaluate the factors contributing to the leases reserve price. Survey protocol begins with an estimation of 'show' factor in permanently marked 1.8 x 45.7 m (2 x 50 yd) 'show' factor plots whose geoduck densities are accurately known from numerous previous visits. This provides the correction factor for all counts of the survey in that region and is done at the start of each survey day. Relocation to another area may necessitate surveying a different 'show' factor plot. Standard transects perpendicular to shore are sampled in the usual way by two divers. The intensity of sampling depends on the area at the site to be auctioned according to the following formula:

Acres to be sampled (ha)	Transects per acre (ha)		Transects surveyed	
			Maximum	Minimum
1 - 5 (0.4 - 2.0)	3.0	(7.4)	15	V.A.T.L.C.
6 - 15 (2.4 - 6.1)	2.0	(4.9)	15	V.A.T.L.C.
16 - 30 (6.5 - 12.2)	1.0	(2.5)	20	V.A.T.L.C.
31 - 50 (12.6 - 20.3)	0.5	(1.2)	V.A.T.L.C.	20
51 - 100 (20.6 - 40.5)	0.3	(0.7)	V.A.T.L.C.	25

V.A.T.L.C. = Varies According To Local Conditions.

Lease areas vary greatly in size, e.g., in 1983 seven leases totalling 174 ha were surveyed. Their average size was 24.9 ha (51.5 acre) with a range of 6.5 to 46.9 ha (16.0 to 116.0 acres). Variation exists to allow both small and large scale harvesters reasonable access to the resource. Small leases are sampled more per unit area to allow for better 95% confidence limits. Not all leases are necessarily purchased each year; some of the 10 or 11 leases made available annually may have been surveyed in previous years.

To maintain the present leasing system, the survey effort supplied by DF is highly streamlined and is further refined each year as their overall data base improves. As an example, data on 8 leases surveyed in 1984 are provided here by L. Goodwin (pers. comm.). Tasks included visiting daily 'show' plots to estimate a 'show' factor correction to be applied to the day's results. Many areas already have established and thoroughly counted permanent show factor plots, which saves much field time. Approximately 200 belt transects were completed and 77 digs (a sample of $\geq$ 10 geoducks) were made for size and meat colour analysis. DF uses a 4-man diving team (to maximize bottom time) and 28 days (field work, lab analysis and report preparation for DNR) of their time was required, i.e., approximatley 0.5 person years of DF time was used to complete survey requirements for the 1984 fishery. Annual

survey costs for this fishery are probably <$U.S. 40,000. Ninety-five percent confidence limits of clam counts ranged between 16 to 50% ($\bar{x}$ = 32%) of the lease stock estimate. A total of 13 leases went on the market and DNR eventually sold 10 for $U.S. 724,572. Lease value varied according to a $U.S. 0.09 to 0.33 per pound rate, depending on clam quality, and the poundage per lease. Some of this income goes towards running both a DF geoduck hatchery and survey costs. Most of the survey work over the years has been done with a combination of State and Federal funds (L. Goodwin, pers. comm.).

(ii) Deep water surveys

There are severe physical limitations on doing extensive SCUBA diving fieldwork at depths >18.5 m. Remote sensing offers a solution for reconnaissance of deep submerged lands. Washington State workers have reviewed relevant remote sensing techniques (Jamison et al. 1984a). Jamison et al. (1984b) surveyed geoducks using a sled-mounted, high resolution TV camera in Case Inlet, Puget Sound, whose depth averaged ≈30 m. Patches of geoducks were found at depths between 18.5 to 111.0 m. Approximately 56 h of survey time were used to survey the 6000 ha site by means of 27 transects, some ≈37 km in combined length. The 0.5 m field of view was divided into 1-minute time intervals from towing speeds of <4 $km \cdot h^{-1}$ along predetermined courses. After 55 days of laboratory analysis, an estimate of 25.8 million geoducks was determined. This depended on 'shows' only and no correction factor was applied to the data. Moreover, it is not known whether there are any characteristic differences between the 'show' factor of shallow water geoducks, more exposed to weather conditions and temperature changes, and that of deeper water populations. In summary, remote sensing generated a geoduck population estimate of unknown accuracy from 6000 ha in less than 15 weeks.

A serious problem of marine remote sensing systems is the calculation of the area covered by the monitoring device (D. W. Jamison pers. comm.). The Washington State vessel moves along a LORAN-fixed course at a low controlled speed. Low vessel speed makes maintenance of course difficult under certain weather conditions and rough water can cause the sled to move erratically over the bottom. Jamison preferred the use of a meter wheel for transect distance estimation over reliance on elapsed time (1 min) segments of tape. There are, however, difficulties with meter wheels and Carney and Carey (1980) suggested that odometer wheels "did not produce estimates of distance towed which could be used without reservation to estimate the density of fauna". Franklin et al. (1980) found counting odometers wheel revolution pings difficult when analyzing videotapes of scallop densities. They preferred using elapsed time (2 min) segements of tape and then counting the 'pings' within the tape segment. Towing speed ranged from 0.9 to 1.8 $km \cdot h^{-1}$ and with a ≈0.5 m wide field, each 2-minute segment corresponded to ≈20 m^2. Whether a bottom-contact odometer wheel or elapsed time at controlled towing speed is best to quantify area of bottom covered will depend on site specific conditions.

There are problems with remote sensing compared to diving surveys (L. Goodwin, pers. comm.). Poor 'show' factor cannot be confirmed by remote sensing whereas divers can probe the sediment to establish the presence of geoducks. Many objects on video tape can mislead the observer. For example,

the difference between Panope, Tresus, and burrowing anemones become hard to discern on tape, but not for divers (L. Goodwin pers. comm.). For counting from video tape, geoducks must have their siphons well extended or be in muddy substrate which permits the formation of large, elliptical siphon holes. In sandy areas of swift currents, poor image quality confounds stock assessment completely, even when geoducks are present in high numbers (L. Goodwin, pers. comm.).

In a comparative remote sensing and diving survey in 9 to 19 m in Hood Canal, divers were able to count high numbers of geoducks, none of which appeared on the video tape of the same area (L. Goodwin, pers. comm.). Geoducks were 'showing' just at the sediment surface and readily covered by current-borne sand which obscured them from the camera but not divers in situ.

IMPROVING STOCK ASSESSMENTS

If managers in British Columbia retain an area quota system based upon a percentage of the estimated stock available, then more reliable stock size estimates will be required. A major survey effort will be required over much of the coast. Priorized objectives enabling improved stock assessment are:

(1) Establish the accuracy of a standard survey technique in waters <18.5 m deep.

(2) Use this technique to survey harvested beds which are the most accessible to fishermen and close to processing facilities.

(3) Survey known, but as yet largely unharvested beds.

(4) Locate and survey virgin beds.

Item (2) alone involves almost 10,000 ha, over 93% of which is in the southern half of the province. Items (3) and (4) may apply more to the northern half.

There are two options:

(a) in situ diving surveys in shallow waters (<18.5 m),

(b) remote sensing of the beds.

The need to survey deep water (>18.5 m) beds is arguable. Firstly, these areas are unaccessible for safety reasons to commercial divers and secondly, it is not known whether deep water populations have a role in the establishment and maintenance of shallow water stocks by contributing larvae and hence should be conserved.

IN SITU DIVING SURVEYS: TECHNIQUES, COSTS AND RECOMMENDATIONS

It would not be possible to avoid some level of diving. Even if remote sensing was used in shallow water, 'show' factor would have to be verified and, therefore, reference plots would have to be established by divers. The advantage of diving is the precision it permits. The disadvantage is the extensive labour required. It will be important in developing this field technique that the trade-off between precision and sampling effort is fully understood.

The first phase of a diving program would be development of an assessment technique. This should involve examination of different coastal areas to reveal their characteristics. Sheltered, easily demarcated small sized beds ≈20 ha each could be selected from different areas such as the east and west coasts of Vancouver Island. Sampling protocol could be:

(1) Document complete harvest history of the site from fishermen's log books and/or previous surveys.

(2) Establish adjacent to each site a permanently marked 'show' factor plot ≈2 x 25 m from which complete counts would be made. This would require numerous counts, perhaps in different seasons to ensure complete censusing of all animals and toestablish local seasonal 'show' factor fluctuations.

(3) Survey the bed to estimate its stock abundance (adjust for 'show' factor).

(4) Permit intensive commercial harvesting in these beds until CPUE became sufficiently low to discourage further harvesting. Harvesting would be permitted regardless of the quota landings for that area.

(5) Intensive post-harvest survey to estimate remaining stock (adjust for 'show' factor).

(6) Assess quality of pre-harvest survey to evaluate the technique.

Item (3) in the sampling protocol of surveying chosen bed(s) can be accomplished efficiently by adjusting quadrate size to average geoduck density. Belt transects between 2 x 5 m and 2 x 50 m permit large numbers of square meters to be sampled much more quickly than through sampling many geographically separated single, square meter quadrats. I recommend firstly completing belt transect counts (n≈30) regularly throughout the bed every 100 m, perpendicular from shore. This regularity, however, violates the central limit theorm (Elliott 1977) that: "the means of a large number of random samples from the same population are approximately normally distributed with a mean equal to the true population mean". Therefore, in the same bed, an equal number of transects situated totally at random should be sampled. The means and 95% confidence limits could then be compared to assess any differences between counts generated by (equal numbers of) regularly versus randomly deployed belt transects.

Washington State DF divers do not sample belt transects within lease tracts at random. Their object is to locate geoducks for commercial harvest within rigid time constraints. They selectively sample areas, excluding ones which their experience dictates will have low stocks. Thus, time and money are saved and the needs of their management system are better served despite the use of less statistically rigorous sampling (L. Goodwin, pers. comm.). A high number of belt transects (for degrees of freedom) is required because 95% confidence limits of stock estimates in beds with few transects can be >±200% of the estimate (Goodwin 1978; Table 3). An acceptable range of 95% confidence limits is ≈32% of the lease stock estimate (L. Goodwin pers. comm.). Belt transects are used in lease tracts up to 50 ha in size. Under optimal conditons, a DF dive team could survey 50 ha and sample individuals for size and meat quality in three days.

A single square meter quadrat technique has neither been assessed nor refined. Nonetheless, a rough cost estimate can be approached according to size of bed (each hectare is to be separately assessed), an estimated mean density of 3 geoducks $\cdot$ m^{-2}, and what a team of two divers can do in one day. Two divers in intensive end-for-end (adjacent) meter squared quadrating can count all geoducks in 300 quadrats per day (B. E. Adkins and R. M. Harbo pers. comm.). A modified technique involves establishing transect bearings out from shore, deploying a transect line end-for-end along the bearing, and counting 1 square meter about every 5 m. At this intensity, perhaps 100 quadrats could be done daily and this would allow ≈4 ha to be sampled (95% C.L. ≈ 40% of $\bar{x}$). With belt transects of 2 x 5 m; established end-for-end along a transect line and with every second one being surveyed, it is estimated that ≈70 transects could be surveyed per day. This would allow ≈6 ha to be surveyed. If surveyors have to collect geoducks for meat colour, etc., then costs (field time) would increase greatly for both methods.

In summary, with the above assumptions, belt transects are slightly more cost effective over square meter quadrats as the sampling unit for <u>in situ</u> diving surveys. But, because this is very dependent on patterns of geoduck distribution, procedures should be routinely reevaluated. The required number of belt transects would be lower than that for single quadrats as the count per quadrate would be much higher. The following table (from Elliot 1977) demonstrates the usefulness of higher mean sample counts for 95% confidence limits. The proportions of the mean used in this example bracket the above-mentioned ≈32% of the mean considered acceptable by Washington State workers (L. Goodwin pers. comm.). This analysis assumes the pattern of distribution is described by a negative binomial and a rough estimate of a common K is 2.

		Mean sample count ($\bar{x}$)*						
	95% C.L.	0.5	1	5	10	20	50	∞
Optimum sample number for	±40% of $\bar{x}$	63	38	18	15	14	13	13
Optimum sample number for	±20% of $\bar{x}$	252	152	72	60	56	52	52

C.L.=confidence limits

*could be geoducks$\cdot m^{-2}$ or geoducks$\cdot$belt transect^{-1}

The time of surveying 120 ha of bed by a 4-diver team using 2 x 5 m belt transects is approximated at 10 field days. Laboratory (computer) analysis, administration, etc, would take perhaps 10 d of one individual's time. Therefore, at 10 person-weeks per 120 ha of geoduck bed, it would require approximately 833 person-weeks (3.2 py), which includes 166 weeks field time for the team, to survey the 10,000 ha of known geoduck beds in British Columbia. Many geoduck areas are relatively isolated, so the dive team would have to operate from a charter boat large enough for full time accomodation. Charter cost of such a vessel is estimated at ~$500/day-1. If a charter boat was needed for 30% of the field time (~50 weeks), total charter costs would be $125,000. If wages and all other expenses are estimated at ~$60,000 per person year, the total survey cost would be ~$315,000 or $3150 per 100 hectares.

REMOTE SENSING SURVEYS: TECHNIQUES, COSTS AND RECOMMENDATIONS

In British Columbia, a remote sensing unit is available for deep water benthic surveys from a private contractor. Assuming a daily cost of $4,200 for the video package, an operator and an accurate position fixing (transect location and tracking) system, a complete remote sensing system is available. The unit would be towed at ~1.8 to 3.6 $km \cdot h^{-1}$ continuously as it is monitored in a deck-mounted module. With the use of a government vessel, an 8 h recording day could yield up to 28.8 km of transect recording, i.e., ~$145.83 km^{-1} of transect. The amount of laboratory analysis days for such production compared to field production would approach 8:1, based on Washington State experience.

Costing of the Washington State system was $US 13,000 for the camera and $U.S. 7,000 for the sled and vessel refit (D. W. Jamison pers. comm.). An estimate of startup R. & D. costs for their system was not supplied. Annual running costs are $U.S. 60,000 to 70,000 for 3 months field work which generates roughly 9 months of laboratory analysis. Approximately 4 h (~16 km of transect) of video tape can be recorded each day. In 60 days of annual field time for data expenses of $U.S. 70,000, it would cost $U.S. 1200 to record 16 km of transect using a government vessel, i.e., ~$U.S. 85 km^{-1} of transect.

In British Columbia the cost of remote sensing is relatively high. It could take 5 field days ($21,000 + lab analysis costs) to become aquainted with the system and develop a field protocol for counting geoducks. Moreover, although extensive area coverage will be possible, the accuracy is unlikely to be reliable and will have to be verified (as will 'show' factor) by diving. I agree with L. Goodwin (pers. comm.) that remote sensing is likely a useful tool only for qualitative monitoring of large, unexplored areas.

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SAVARY ISLAND CLAM STUDY

by

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ABSTRACT

Savory Island, which is located in the northern Strait of Georgia, is an important harvest area for steamer clams: littleneck, Protothaca staminea, and manila, Tapes philippinarum. Surveys were begun in 1978 to assess steamer clam populations on the beach off the north coast of the island and have continued to the present. Information from these surveys was used to study fluctuations in clam populations and to set quotas for commercial and recreational fisheries. Results of these surveys show that littleneck and manila clams are the commonest commercial bivalve species on the beach. Populations of manila clams have always been greater than those of littleneck clams. Density of manila clams has ranged from a low of 15.7 m^{-2} (legal and sublegal size) to a high of 423.8 m^{-2} and for littleneck clams from 3.0 m^{-2} to 37.3 m^{-2}. Recruitment of littleneck clams has generally been low and consistent but for manila clams it has increased in recent years. The quota appears to have had little effect on steamer clam populations and it is suggested the best method to regulate the fishery is by size limit.

INTRODUCTION

Savary Island is a long, thin, new-moon shaped island in the northeastern part of the Strait of Georgia (Fig. 1) with steep cliffs on the southern and northern edges. The intertidal area on the south side is limited and mostly rock and rock reefs. On the northern side there is a large intertidal sand-mud beach seaward of the cliff with many large boulders (Fig. 2).

Extensive clam populations occur in the intertidal beach off the north side of the island. Butter clams, Saxidomus giganteus, were harvested there at one time but in the last 15 years landings of this species have been virtually nil; they are not a target species in the present commercial

fishery. Steamer clams, littleneck, Protothaca staminea, and manila, Tapes philipinarum, are abundant on this beach and have been harvested for many years, in recent years the main fishery has been for manila clams. The harvest was at low levels for many years because of limited markets and low prices. In the mid 1970's markets changed and there was a shift in target species in commercial clam fisheries in the Strait of Georgia from butter to steamer clams (Ketchen et al. 1983). Steamer clam populations at Savary Island came under heavy digging pressure in the late 1970's which has continued to the present. The local Fishery Officer estimates that at least 50% of clams landed from statistical area 15 in recent years came from the beach off the north shore of Savary Island (N. Armstrong pers. comm.).

In 1978 a conflict developed between residents of the Island and commercial clam diggers. The local Fishery Officer requested that sampling be undertaken to assess steamer clam populations on the beach. Regular annual or semi-annual surveys continued since then and have provided information on littleneck and manila clam populations and recruitment on this beach. Annual quotas for the commercial fishery that were 50% of the standing stock of legal size clams were established from these surveys. Results of the work are reported here.

METHODS

Sampling procedures varied slightly from year to year depending on personnel available. Width of the intertidal beach varies from about 50 m at the narrowest to about 0.8 km at the widest. Virtually all recent clam landings from Savary Island have been steamer clams and it was decided to concentrate sampling in the intertidal zone where these clams are most abundant; i.e. from the 1 m to the 3 m intertidal level, the former level at Savary Island occurs at the break at the upper edge of the beach.

Sample plots were marked out that were 1 m^2 in area and dug to a depth of 12 cm with a short handled rake. If clam abundance was high the plot was subdivided into 0.5 or 0.25 m^2 areas. The soil was carefully sifted through the fingers and clams removed. The soil was reworked back into the plot by sifting it through the fingers and the remaining clams removed. Past research has shown this method is efficient at collecting about 95% of clams 20 mm shell length and larger. Sieving samples through a screen would insure that all clams were collected, including those less than 20 mm, but this is time consuming and was not deemed practical for this work.

Clams from the plots were returned to the Pacific Biological Station and shell length and in most samples shell height measured with vernier calipers to the nearest mm. Clams were also weighed to the nearest 0.1 g. Length frequency histograms were plotted for all species. Whole weight was plotted against shell length for littleneck and manila clams to estimate parameters for the standard weight-length expression, $W=aL^b$. The program ALOMA (Piennaar and Thomson 1973) was used for the regression analysis.

Growth was determined by two methods. Shell length at winter annuli was measured to the nearest mm (Quayle and Bourne 1972) for samples of

littleneck and manila clams. Age was also determined by counting the number of annuli and recording the total length of the clam. Adjustment was made for the season in which the clam was dug. Mean shell lengths at annuli and age were used to estimate parameters for the Von Bertalanffy growth model using the program VONB (Allen 1966).

Clam biomass was determined by calculating mean clam density per m^2 and estimating the clam bearing area of the beach.

All data are stored on magnetic tapes at the computer facility of the Pacific Biological Station, Nanaimo, British Columbia.

1978 Sampling

Nineteen random samples were taken on the eastern half of the beach off the north side of the island, from about 0.5 km west of the wharf to just past the second point. All samples except two were in the upper part of the beach.

1979 Sampling

In 1979, 54 random samples were taken along the entire beach, all were in the upper part of the beach.

1980 Sampling

No samples were taken in 1980.

1981 Sampling

In 1981 two types of sampling were undertaken.

In February, 34 random plots were dug along the entire beach, all were in the upper part of the beach.

In 1981 it was decided to undertake a more intensive sampling program to determine the distribution of littleneck and manila clams more precisely. This sampling program was undertaken in July. Twelve transects were established more or less evenly over the part of the beach that is harvested commercially. Each transect ran from the waters edge to the break at the top of the intertidal beach (Fig. 3). Samples were dug at 25 m intervals in Transect A and at 50 m intervals in the other transects.

1982 Sampling

In 1982 sampling was carried out twice, 22 samples were taken in March and 24 samples in October; all were in the areas of littleneck and manila clam abundance as determined in the July 1981 sampling.

1983 Sampling

In 1983, sampling was carried out twice, 20 samples were taken in March and 25 samples in October; all were in the areas of littleneck and manila clam abundance.

1984 Sampling

In 1984 a single sampling was undertaken in May and extended further seaward on the beach since commercial quantities of manila clams were found up to 400 m from the top of the beach. Thirty random samples were taken in two areas, around the first and second points and along the clam bearing area at the western end of the beach. Shell length of clams of only 5 randomly chosen plots were measured to the nearest mm for length frequency analysis.

RESULTS

Distribution

Manila and littleneck clams are the major clam species on the beach off the north side of Savary Island. A few butter clams were found at the lower levels of the beach, below the 1.3 m tidal level, but densities were less than 1 m^{-2}. Large quantities of dead butter clam shell was found in a few locations indicating there may have been greater populations of this species in previous years. A few Macoma sp. and cockles, Clinocardium nuttalli, were found mostly in the lower part of the intertidal beach.

Manila and littleneck clams were found in varying abundance over much of the beach but were most abundant in the upper 200 m of beach. In the 1984 sampling commercial quantities of manila clams were found in the upper 400 m of beach in the area around the first and second points. There appeared to be three centers of populations (beds) on the beach: - in a gravel ridge about one hectare in area at the western end of the beach; in an area eastward of the gravel ridge and in another bed centered around the first and second points (Fig. 4).

Growth

Winter annuli of manila and littleneck clams were generally distinct and could be measured readily. Growth rates of littleneck and manila clams are shown in Figures 5 and 6. Manila clams attain the legal size of 38 mm (1.5 inches) shell length in about 3.5 years; littlenecks have a slightly slower growth rate and attain the same size in about four years. This is as rapid a growth rate for these two species as recorded in British Columbia.

A significant percentage of manila clams were stunted. Initial growth until 2-3 years (25-35 mm shell length) is normal but it then slows drastically and virtually stops when the clams measure about 40 mm shell length. The ventral margin of the shell convolutes and thickens and the

entire shell also thickens. The shape of the clams can also be greatly distorted. Stunted clams were more common in populations that occurred high up on the intertidal beach. They were also more common when densities were higher. If large numbers of stunted clams are used for aging it can lead to bias in estimating growth rates at older ages.

Size frequency distribution

Size frequency distribution of littleneck and manila clams is shown in Figures 7 and 8.

There was a general wide distribution of littleneck clam sizes that ranged from 10-55 mm shell length during the period of sampling. In the first two years; (1978 and 1979) there was a preponderance of littlenecks above the legal size of 38 mm shell length. In subsequent years most littlenecks were below the legal size except in the widespread sampling of July 1981. Few dominant year classes were observed during sampling except in February 1981 and September 1982, indicating recruitment was consistent and at low levels.

Size range of manila clams was generally slightly smaller than that of littleneck clams. In the first two years most clams were above the legal size of 38 mm shell length. In 1981, numbers of legal and sublegal sized manila clams were about evenly divided. In subsequent sampling there was a dominance of clams smaller than the legal size indicating there was good recruitment in recent years. Strong modes indicating possible good year classes were observed in February 1981, September 1982, and May 1984.

Clam densities

Densities of littleneck and manila clams during the sampling period are shown in Tables 1 and 2 and Figures 9 and 10. Densities of legal and sublegal size littleneck clams were much lower than those of manila clams.

Densities of legal size littleneck clams were low during the sampling period and fluctuated from a low of 1.6 m^{-2} in February 1981 to a peak of 9.4 m^{-2} in October 1983 (Fig. 9). The density of sublegal size littlenecks was low until 1981 then increased and since that time has been above 13.5 m^{-2} indicating that recruitment has been low but consistent in recent years.

Densities recorded in July 1981 were low because sampling covered the entire beach including the lower part where there are few littleneck and manila clams. Sampling in other years was confined to the littleneck and manila clam bearing part of the beach.

Densities of manila clams show a somewhat similar pattern to those of littlenecks. Densities of both legal and sublegal size manila clams have been higher since 1981 (Fig. 10). Since 1981 densities of sublegal size manila clams have generally been above 200 m^{-2} indicating strong recruitment in recent years.

DISCUSSION

Abundance of both littleneck and manila clams on Savary Island beaches varied widely during the period of sampling. Littleneck recruitment was fairly constant but at low levels whereas, manila clam recruitment was consistently high during the same period despite an intensive fishery for this species. Although abundance of sublegal stock increased for both species it is not possible to attribute this to either the fishery or environmental conditions. It is doubtful however, that management by quota resulted in these observed changes.

No biological rationale exists for the present quota or partioning of clam stocks on Savary Island. Both littleneck and manila clams have a natural larval period of at least three weeks and larvae produced from any beach could be widely dispersed prior to settlement. Clams recruiting to Savary Island beaches may have originated from any of the clam beaches in the surrounding area. Both species have a relatively short life span, they enter the fishery after 3.5 years and experience high natural mortality after five or six years. Hence maintaining a large legal stock of clams on Savary Island may have no positive effects on recruitment but could result in considerable loss of production.

Currently, the commercial clam fishery in British Columbia, with the exception of Savary Island, is managed through a minimum size limit and sometimes seasonal closures. These size limits are set to insure the clams are capable of spawning at least once and probably twice before entering the fishery. This is the most expedient way of managing clam stocks provided the size limits are rigourously enforced.

Table 1. Mean number of legal and sublegal size littleneck clams per square meter on beach at Savary Island 1978-1984.

Date	Mean number littleneck clams	
	Legal	Sublegal
March 1978	3.16	1.37
December 1979	7.69	3.09
February 1981	1.6	2.2
July 1981	1.7	1.3
March 1982	6.36	20.36
September 1982	4.3	33.0
March 1983	3.4	13.5
October 1983	9.4	22.9
May 1984	3.0	19.8

Table 2. Mean number of legal and sublegal sized manila clams per square meter on beach at Savary Island 1978-1984.

Date	Mean number	
	Legal	Sublegal
March 1978	13.5	6.2
December 1979	16.3	18.6
February 1981	34.2	40.8
July 1981	6.6	9.1
March 1982	88.2	236.6
September 1982	35.1	159.7
March 1983	62.9	213.4
October 1983	89.6	334.2
May 1984	32.8	258.0

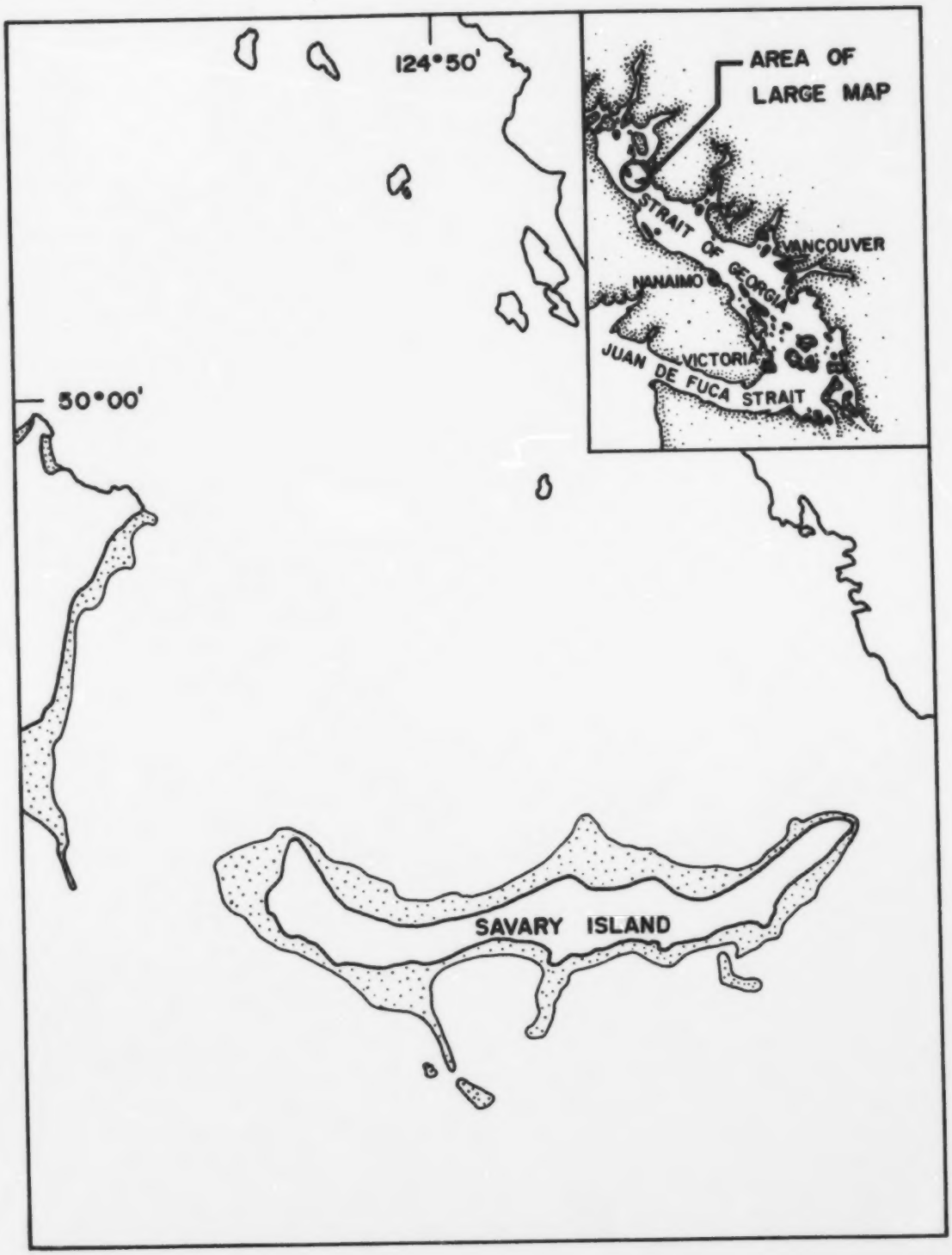

Fig 1 Strait of Georgia and the location of Savary Island

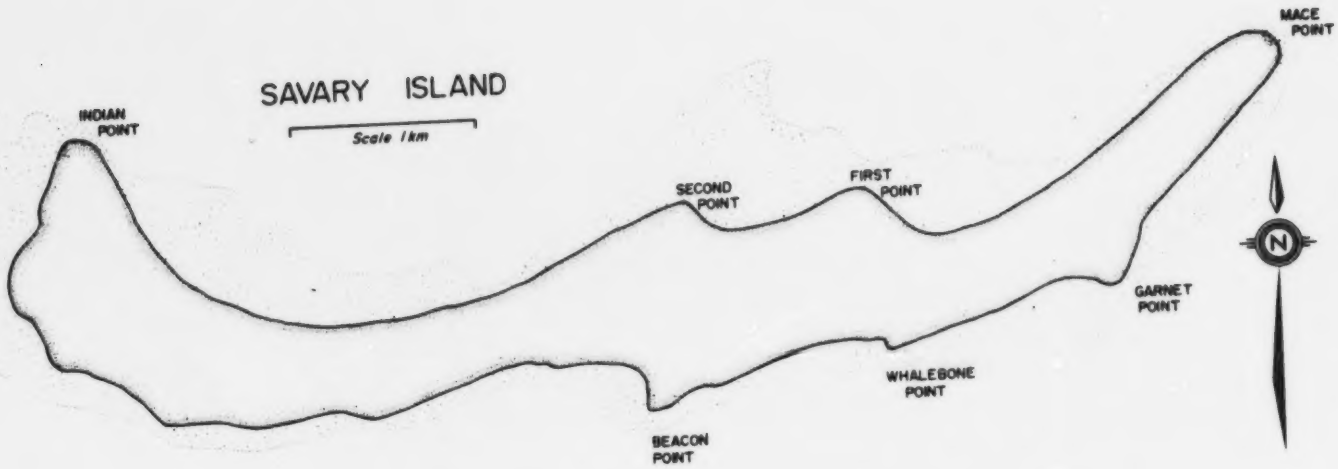

Fig 2 Savary Island and the location of rock reefs off the southern part and the clam beach off the northern part of the Island

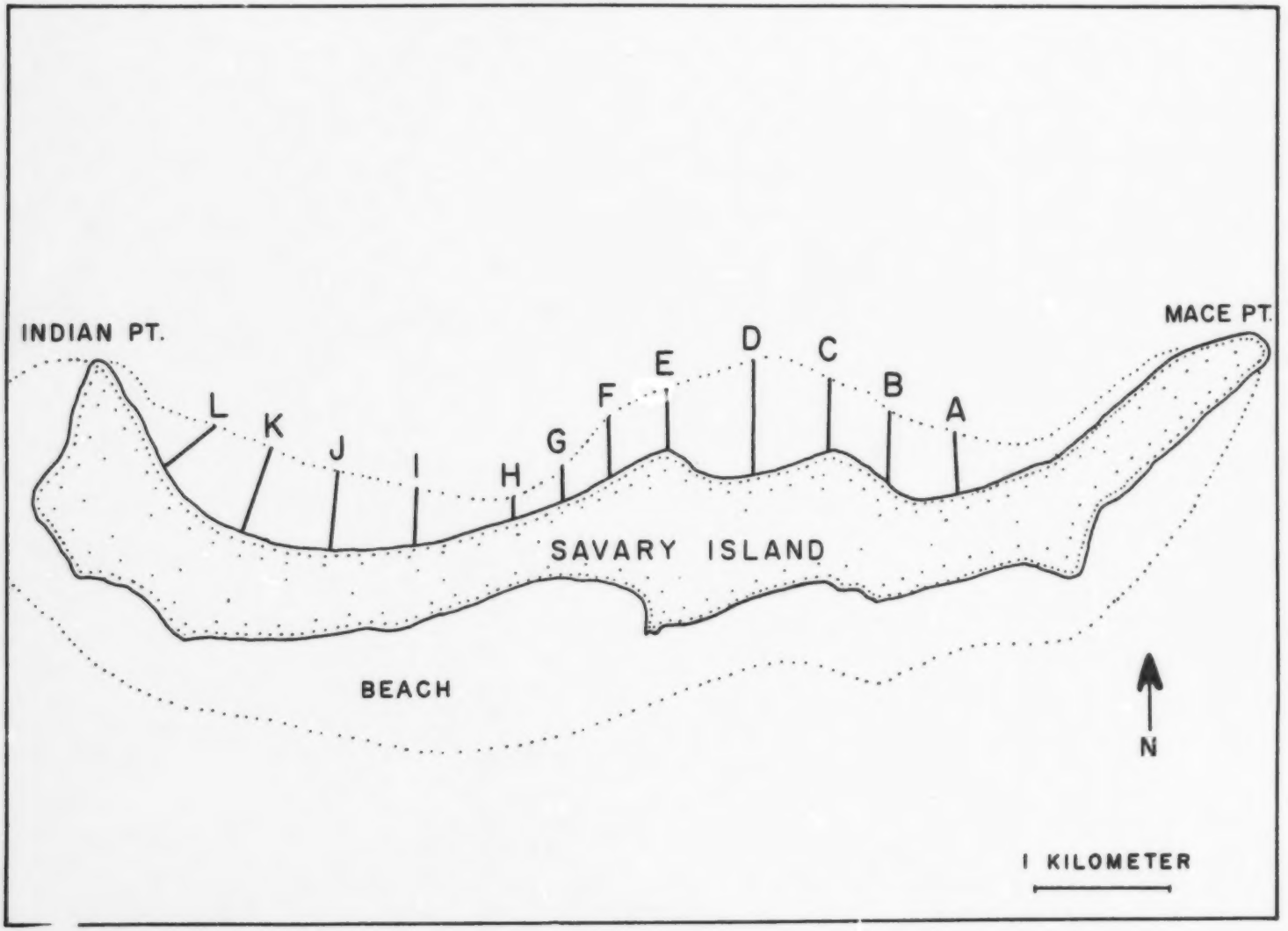

Fig 3 Location of the twelve transects in the July 1981 survey on Savary Island

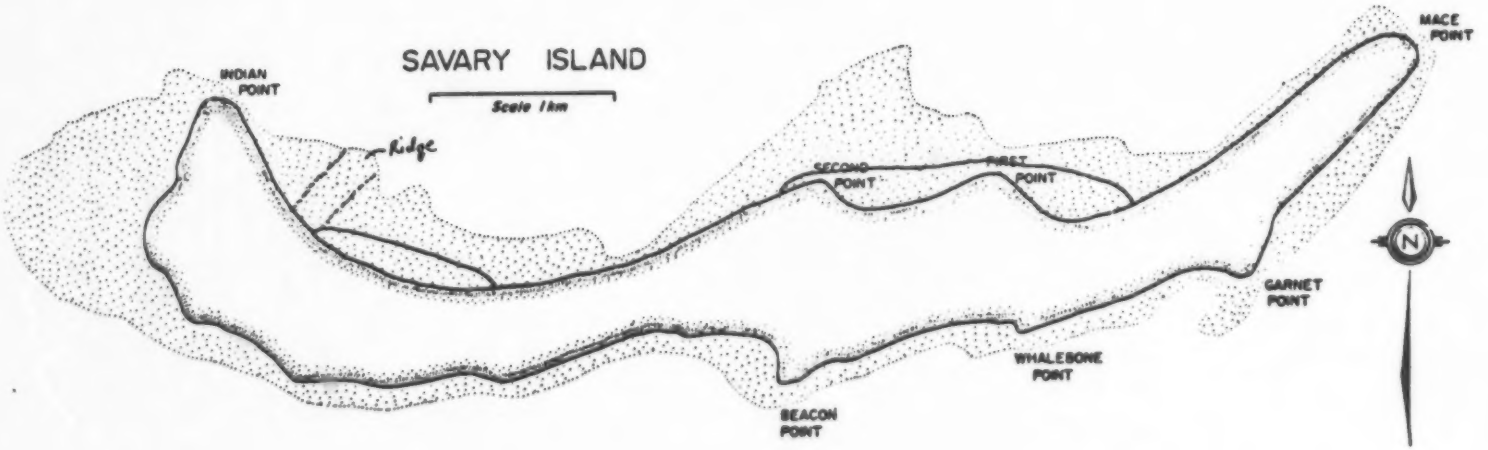

Fig 4 Location of main clam beds on the beach off the north side of Savary Island as determined after the 1981 survey

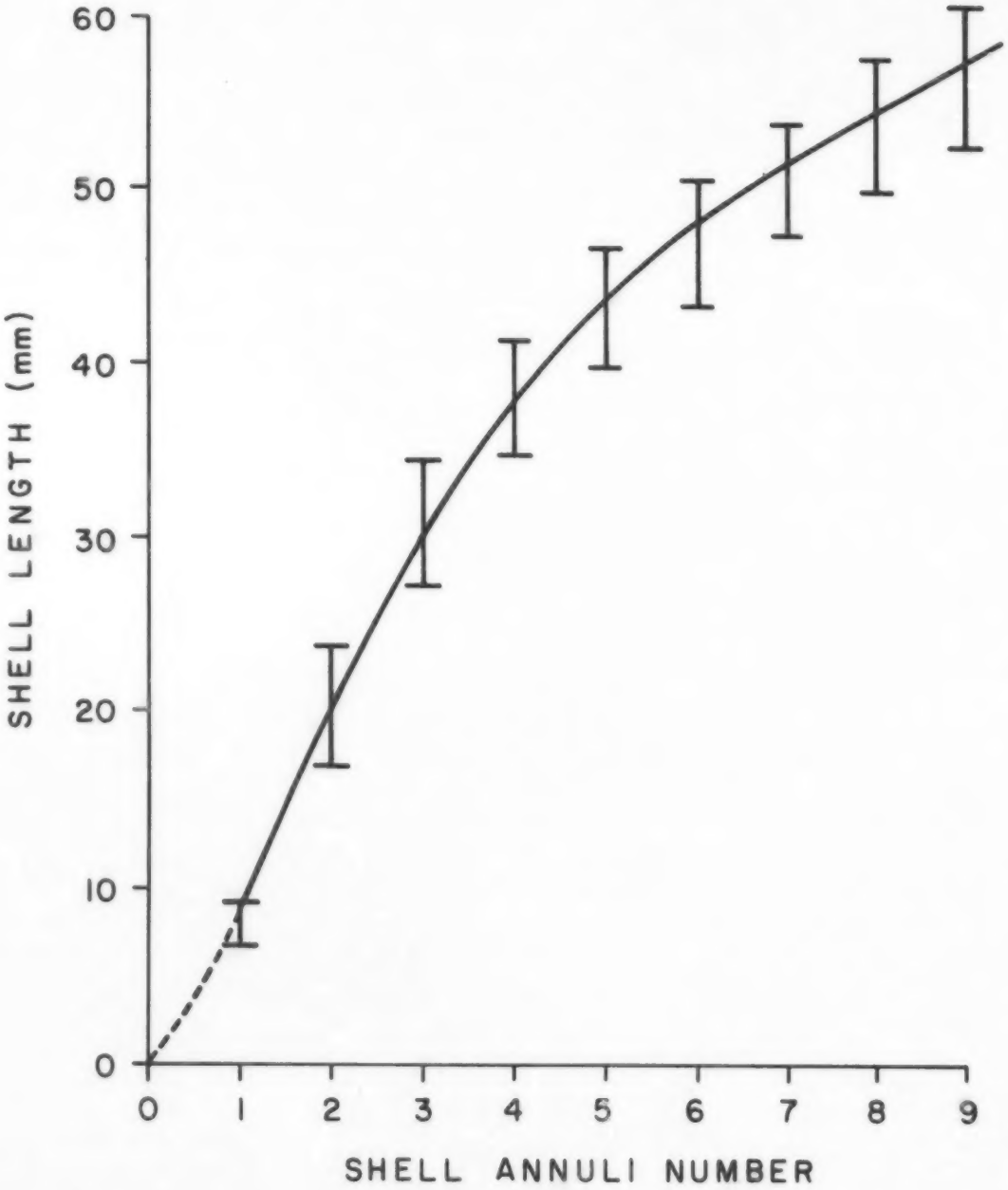

Fig 5 Growth rate of manila clams at Savary Island

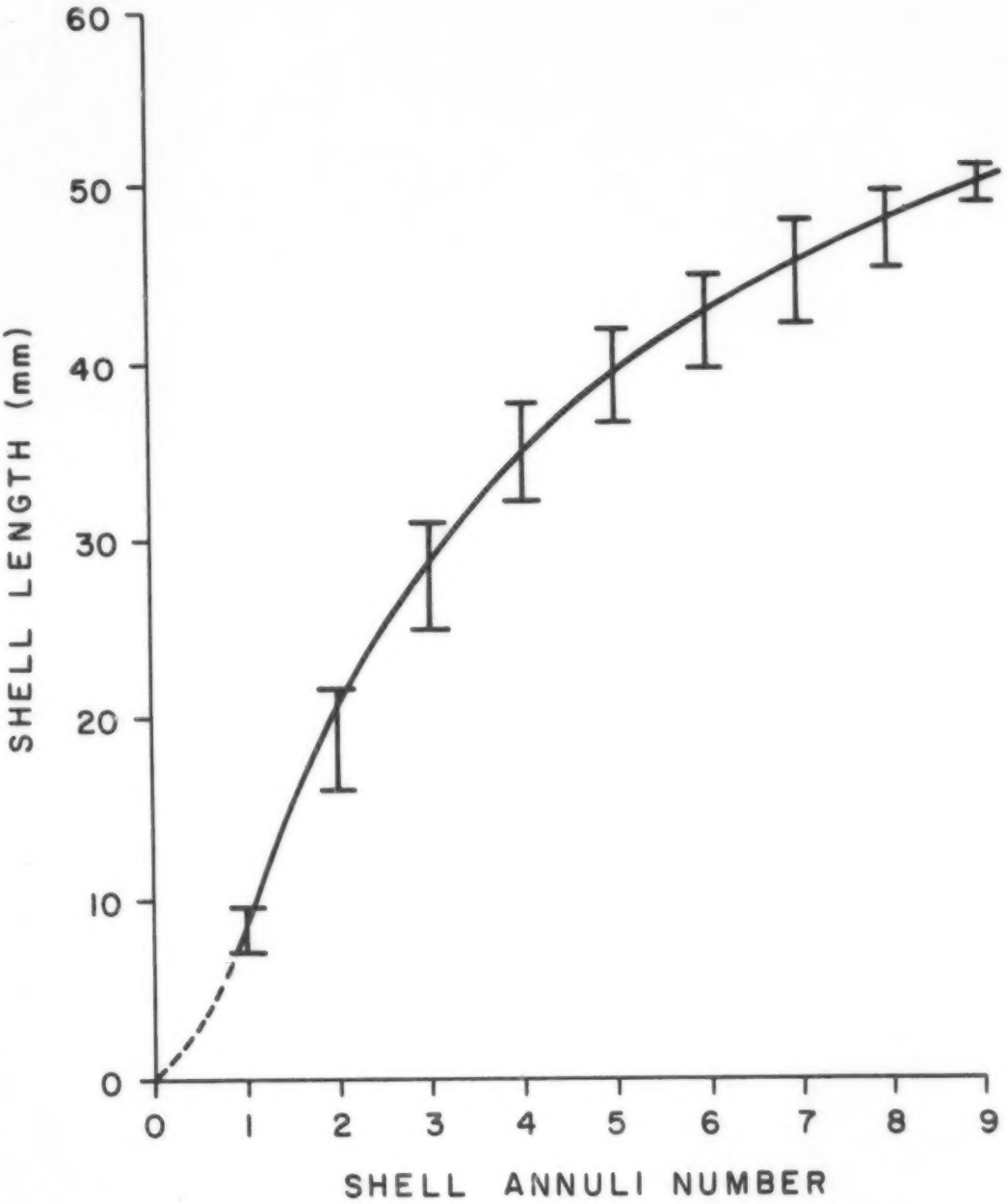

Fig 6 Growth rate of littleneck clams at Savary Island

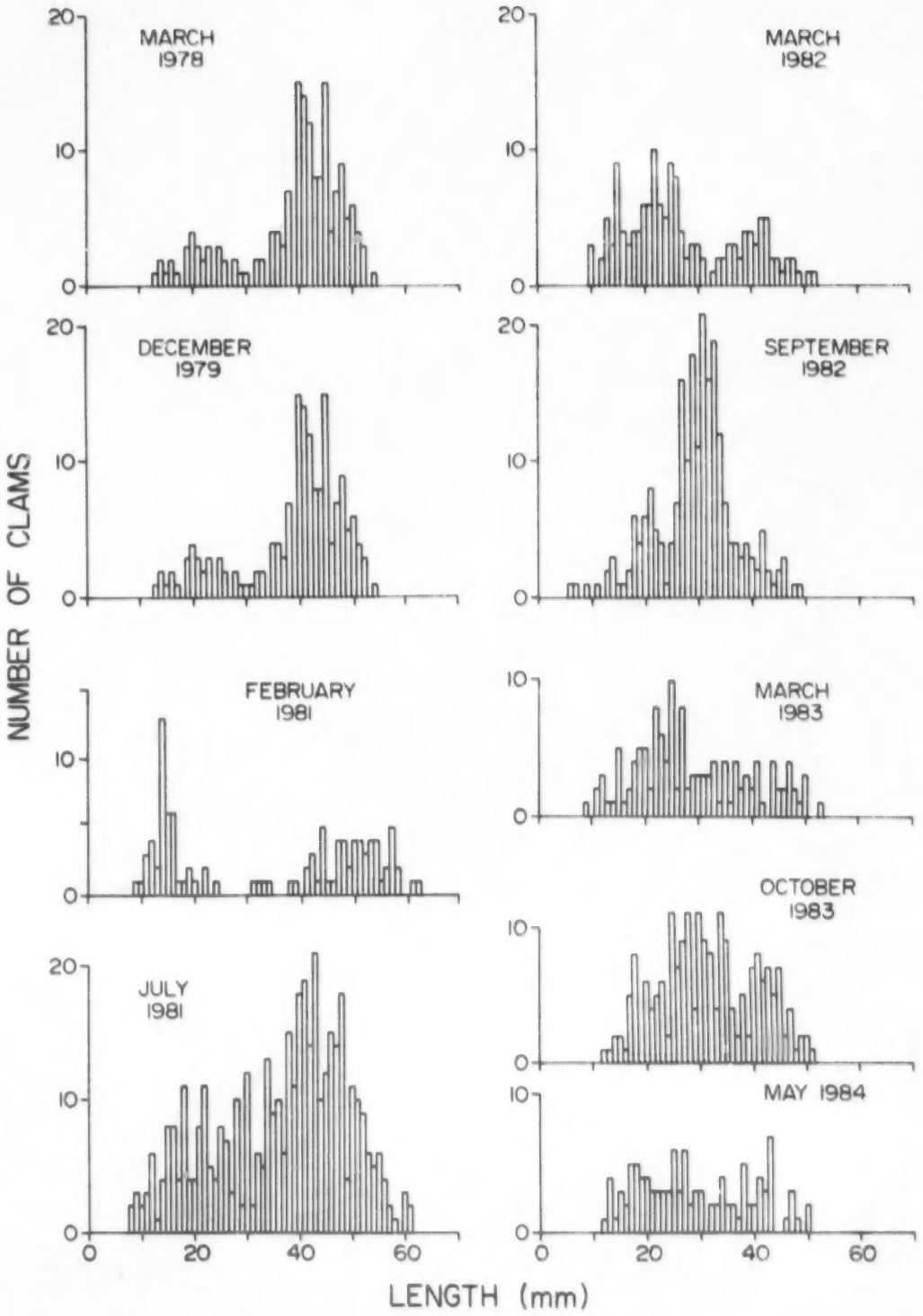

Fig 7 Size frequency distribution of littleneck clams collected at Savary Island, March 1978 to May 1984

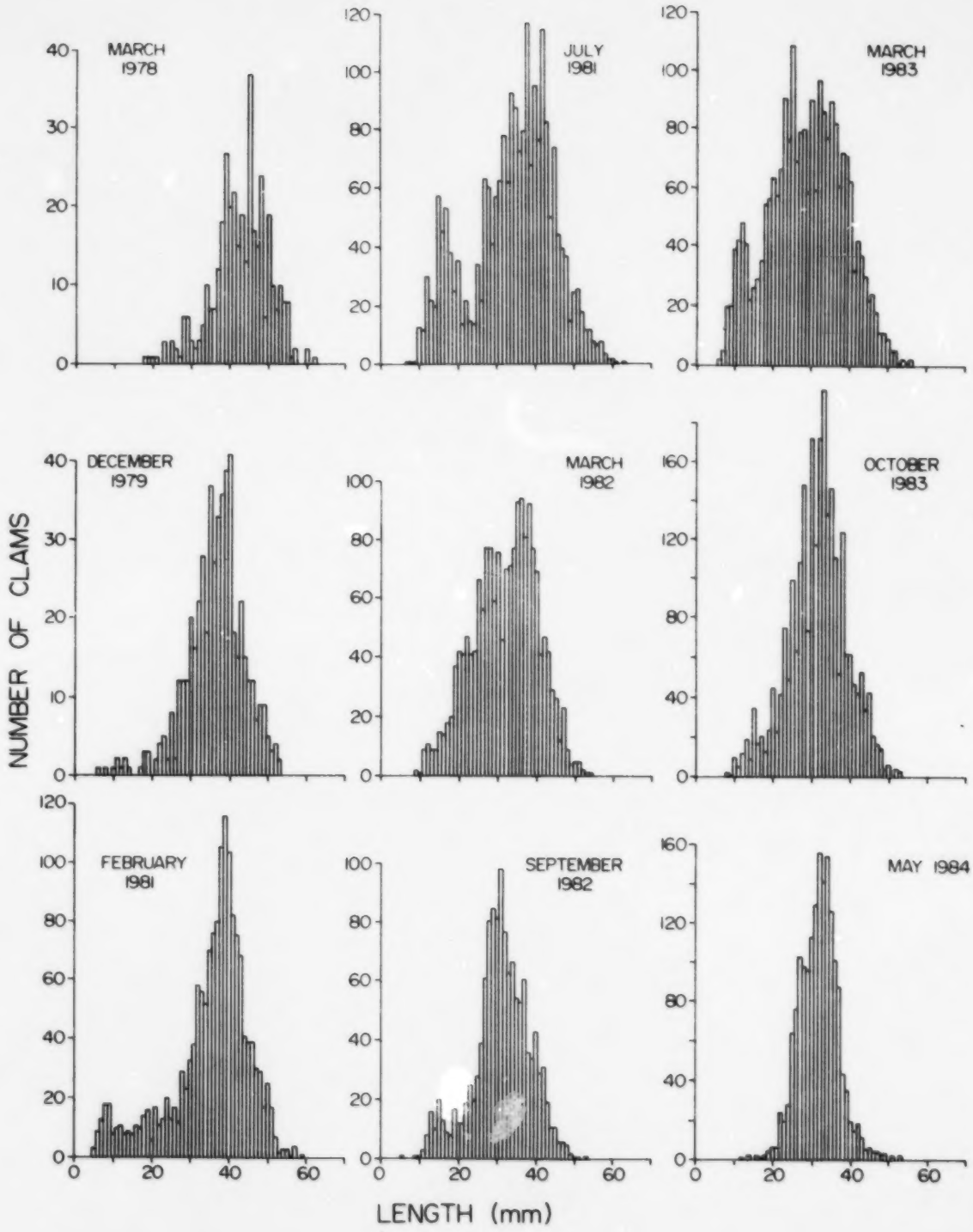

Fig 8 Size frequency distribution of manila clams collected at Savary Island, March 1978 to May 1984

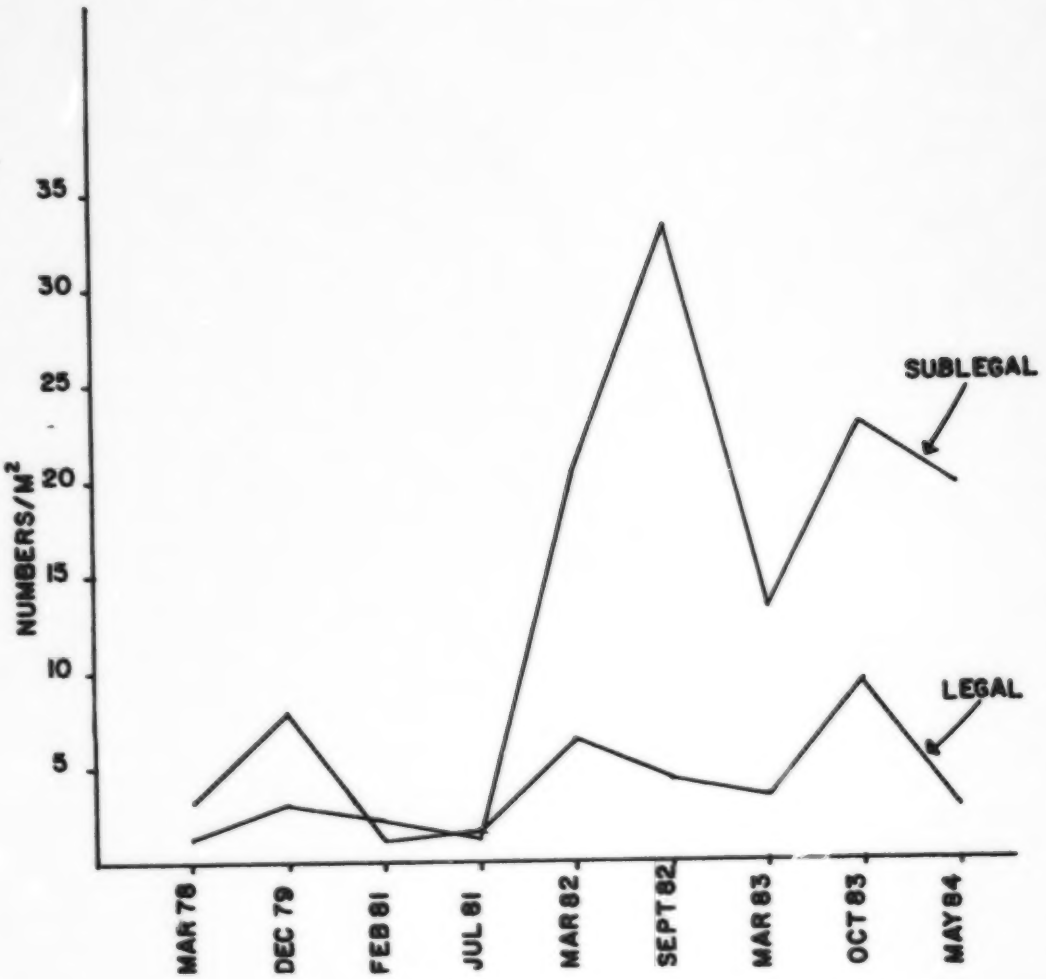

Fig 9 Mean density of legal and sublegal size littleneck clams collected at Savary Island, March 1978 to May 1984

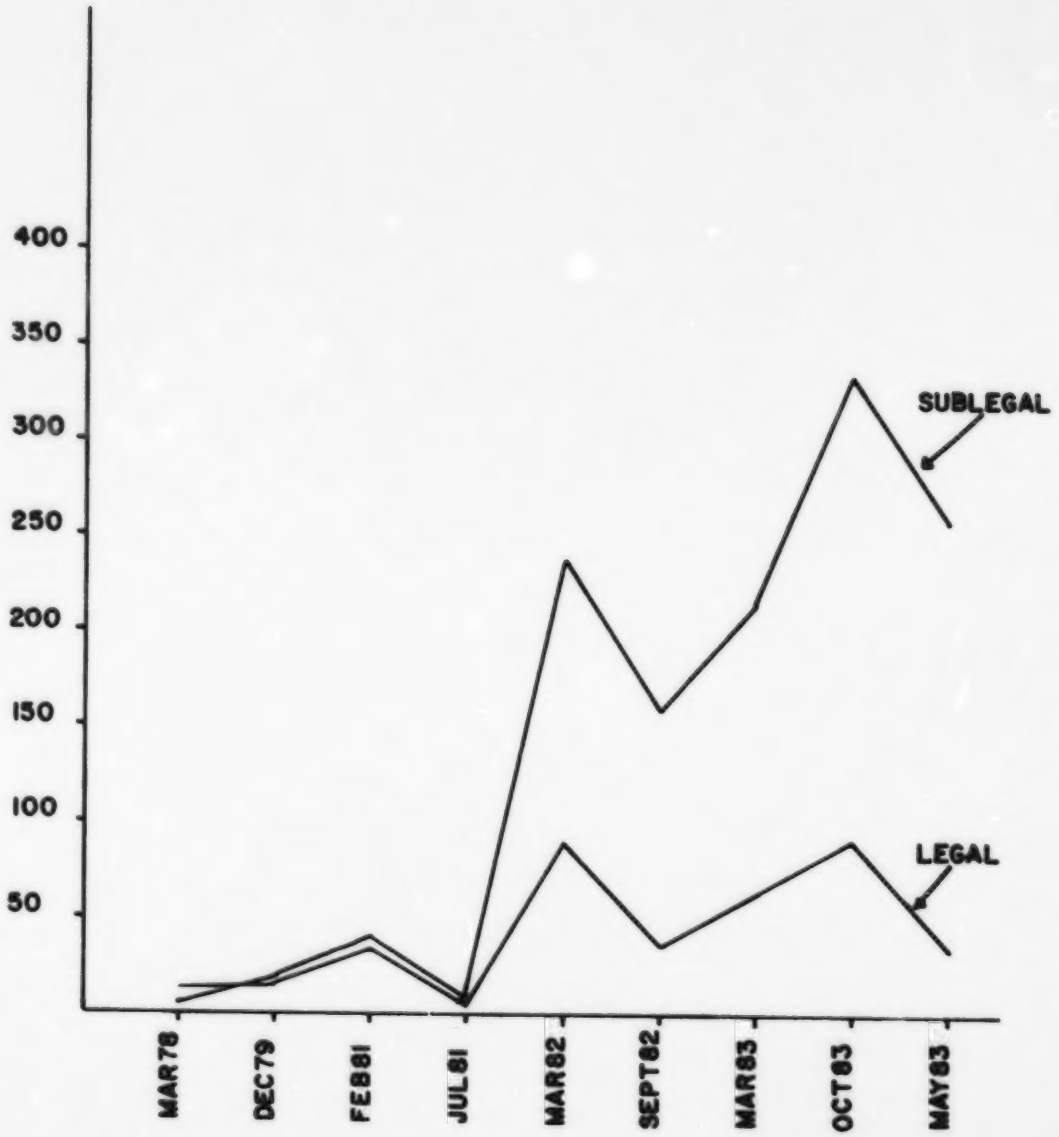

Fig 10 Mean density of legal and sublegal size manila clams collected at Savary Island, March 1978 to May 1984

SCALLOP BREEDING STUDIES

by

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ABSTRACT

An initial requirement in studies to determine the feasibility of scallop culture in British Columbia is a supply of juveniles (seed), and attempts to breed four species of scallops are described: two native species, weathervane, Patinopecten caurinus and rock, Chlamys gigantea, and two exotics, Japanese, Patinopecten yessoensis and sea, Placopecten magellanicus. Most research has been with the Japanese scallop and methods to condition and spawn adults, raise larvae, species and amount of algal foods used, and methods to settle spat are described. Maximum larval growth from time of spawning to settlement was 25 days but for most larvae it was 30-40 days. At settlement larvae measured 250-270 µm. Heavy mortalities were experienced at metamorphosis and in early juveniles, and work to improve survival at these stages is described. Results of attempts to breed weathervane, rock and sea scallops are described.

INTRODUCTION

Thirteen species of scallops have been recorded from British Columbia waters but most are small or rare (Bernard 1983). Four species are large or occur in sufficient abundance to elicit enquiries about the possibility of a commercial scallop fishery: - weathervane, Patinopecten caurinus; rock, Chlamys gigantea; pink, C. rubida and spiny, C. hastata, (Bourne 1969). Weathervane scallops are large and there are a few small centers of concentration along the coast, e.g. the Gulf Islands and Dixon Entrance. However, these beds are too small and scallop populations too sparse to support a continuing fishery of any magnitude. Rock scallops are also large and have a patchy distribution along the coast. They are firmly cemented to rocks and do not lend themselves to a dragging type fishery. Present regulations prohibit commercial harvest of rock scallops. Pink and spiny scallops occur in small beds that are erratically distributed along the coast. There is a small fishery for these two species but populations are limited and the fishery will probably remain small.

Natural scallop resources in the Province are not sufficient to support a significant commercial industry, i.e. annual landings of 1,000 t or more. Development of a scallop industry of any magnitude will depend on a culture or enhancement operation. Based on this premise a project was begun at the Pacific Biological Station in 1982 to investigate the feasibility of scallop culture in British Columbia.

SPECIES

An important consideration in the project was selection of suitable species for culture. Major national and international markets only utilize the adductor muscle. The small British Columbia fishery for pink and spiny scallops is dependent on markets utilizing the whole scallop but the size of this market is unknown and may be small. If this market expands it could be supplied with smaller sizes of larger scallop species. The three criteria used in selection of species for the project were: 1) size of the adductor muscle, 2) rapid growth rate, and 3) availability of brood stock.

Two native species met these criteria and were selected for study, weathervane and rock scallops. In addition, a decision was made to investigate the feasibility of culturing two exotic species, the Japanese scallop, Patinopecten yessoensis and the Atlantic sea scallop, Placopecten magellanicus. Both species are large and have rapid growth rates. The Japanese scallop is widely cultured in Japan and there have been studies on the east coast to investigate the feasibility of culturing sea scallops.

SEED SOURCES

Seed for bivalve culture can be obtained in three ways; purchase it from areas where it occurs in abundance, collect it locally from natural sets, or produce it in a hatchery.

No sources are known where large quantities of scallop seed can be purchased for culture operations other than perhaps Japan for Japanese scallop seed. This source of seed was eliminated because of the possibility of importing pests, parasites and diseases with the seed. Further a foreign country would essentially control the industry since it would control the source of seed. It was believed that importing seed would proved too expensive.

Attempts were made to collect natural weathervane scallop sets for three years, 1981-1983, but results were disappointing. Methods used were similar to those used in Japan, (Taguchi 1977; Ventilla 1982). Collectors were put out in Trincomali Channel in the Gulf Islands in June and recovered in October. Ten juvenile weathervane scallops were caught in 1981 but none in the following two years because of heavy sets of the crab, Cancer oregonensis, which would have eaten any scallop spat that settled in the collectors.

Pink, spiny and rock scallop spat have been caught on various types of collectors including oyster rafts at several locations throughout the Province but numbers have generally been low. Whether sufficient seed of

these three species can be collected on a reliable basis to support any sizeable industry is unknown but it warrants investigation.

We decided to develop hatchery methods to produce sufficient scallop seed for a pilot scallop farm operation. The project was begun in 1982 and all work has been done at the Pacific Biological Station.

Most breeding studies have been with the Japanese scallop and in this report results of this work are discussed first. Results of breeding work with the other species are summarized briefly at the end.

BROODSTOCK

Broodstock Japanese scallops has been imported to the lab under quarantine conditions in 1983 and 1984 from the Aquaculture Center of Aomori Prefecture at Mutsu Bay in Japan through the kindness of the Director, Dr. Susumu Ito. In 1984 five shipments were received from February through March, a total of 250 animals; mortalities were less than 5%.

No attempt has been made in our work to condition scallops from the spawned out stage to a ripe condition. We have obtained sexually ripe adults by following the gonadal condition index and have used them for breeding studies. The gonadal condition index of scallops received from Japan ranged from 22-34%. The index was maintained by holding scallops in 7-10°C sea water and feeding them regularly.

SPAWNING

Spawning was attempted the day after stock was received from Japan but more consistent results were obtained when animals were held for at least one week and fed daily. Some scallops spawned several times over a period of four months.

Several methods were used to induce spawning, initially the most reliable method was thermal shock. The general spawning procedure was to remove ripe scallops from the holding tanks and immerse them in sea water in the spawning tray that was 9-13°C, (2-3°C higher than the holding temperature). If spawning did not begin within an hour the water temperature was raised a further 2-3°C and large quantities of food and/or sperm suspension added.

Another method that was successfully used was injection of 0.4 ml of 2×10^{-5} molar solution of serotonin into the adductor muscle of ripe scallops. An immediate response was observed, the animals clapped their valves violently and the foot was greatly extended. Spawning usually occurred from 15 minutes to one hour in males and from 30 minutes to two hours in females, spawning occurred in 90% of males and 50% of females.

Spawning could extend over a period of six hours with periods of quiesence interspersed with periods of activity. Spawning could usually be stopped by putting the animals in 2-3°C sea water.

The spawned eggs were 80μ in diameter. Sperm was added to the water containing eggs and fertilization generally occurred within 15 minutes. Fertilized eggs were gently washed to remove excess material and placed in sea water at 14°C to give a concentration of 10-30 eggs per ml. The fertilized eggs developed to the trochophore stage in 1-2 days and to the veliger stage in 2-3 days. At this time the tanks were drained and larvae put in fresh sea water at a concentration of 1-2 larvae per ml.

LARVAL REARING

Larvae were reared in tanks ranging in size from 350 to 6,000 liters. Water was changed every 48 or 72 hours. At each water change the water was siphoned through nitex screens which varied in size depending on the size of the larvae. The larvae were counted and graded through a series of nitex screens if there was a noticeable size range in the larvae. A sample was taken to measure growth (shell length), and observations were made daily of the larvae to determined their state of health.

Larvae were raised at temperatures ranging from 12-18°C but mostly at 15°C since this temperature gave most consistent results.

Ambient salinity (29°/₀₀) ± 1°/₀₀) was used throughout the work. According to Japanese literature, this salinity is a bit low but our results indicate fertilization and larval development occur satisfactorily at this salinity.

Considerable time was spent trying to find the best algal foods to produce good growth and survival. Algae used have been reported as foods for other bivalve larvae. The foods we have used most consistently, both singly and in combination are: - Isochrysis galbana (Iso); Tahitian Isochrysis (Tx); Chaetoceros calcitrans (CC); and Thallassiosira pseudonana (3H).

Growth rate varied considerably depending on the species of algae used as food (Fig. 1). In cultures with the best growth rate, larvae grew to the setting size of 260μ in 22 days; the mean was about 32 days to 250μ shell length.

In February the combination of CC and Iso produced optimum growth rates but this growth rate could not be repeated later in the year. Isochrysis alone did not produce optimum growth. CC and 3H when used in combination tended to produce a stepwise growth pattern and larvae reached setting size only after 30-40 days (Fig. 2). Optimum growth of less than 25 days from fertilization to metamorphosis occurred only when a mixture of CC and Tx was used (Fig. 2). This mixture also gave the highest lipid content in larvae when they were stained using the method of Gallager and Mann (1981).

We found that mean to fastest growth was sustained using a combination of equal numbers of Tx and CC at the following regime. During the

first week, when larvae were 115-140μ, they were fed 5-15,000 cells/larva/day. In the second week when larvae measured 140-190μ the ration was increased to 15-30,000 cells/larva/day. For the final week when the larvae were 190-260μ they were fed 30-60,000 cells/larva/day. Feeding rates were adjusted daily within these ranges depending on observations of tank colour and larval gut contents.

Eyespots began to develop when the larvae reached a shell length of 235μ. Metamorphosis occurred when the larvae were 250-270μ with a mean length at 260μ and the eyespot at this time measured 5-10μ in diameter.

Survival rates were highest when larval density was 1-2 larva/ml in the first week, which was reduced to 1 larva/ml in the second week and to 0.3-1 larva/ml in the third week. Densities were purposely reduced in our work to provide healthy larvae at metamorphosis.

Highest survival from fertilized eggs to straight hinge was 30% but the mean was much lower, 10%. From straight hinge to metamorphosis the highest survival was 41% and the mean about 10%.

A variety of cultch material has been used to set larvae but the best to date has been polypropylene rope, 200-350μ oyster chips and astroturf. Cultch was placed in static systems (350 l tanks) and in downwelling systems made of 15 cm PVC pipe with 180μ nitex screen. Water was circulated through the downwellers with air lift pumps. In the downweller systems the initial set was between 50-80% but when the spat were about 400-500μ heavy mortalities occurred. The same pattern developed in the static system but the spat were difficult to sample. Upwelling systems were tried to minimize post settlement mortalities but proved to be no better than static or downwelling systems. Mortalities in all these setting systems were heavy and no juveniles survived to a shell diameter of 1 mm.

Presently we are using a modified downwelling system to set larvae, nitex screens of 165μ mesh that measure 30 x 45 cm and have a water flow with a greater horizontal component. With this system there have been fewer mortalities and at present we have about 300 spat ranging in shell diameter from 1-2 mm.

WEATHERVANE SCALLOPS

Broodstock weathervane scallops were collected from Trincomali Channel in the Gulf Islands from March through May; natural spawning of this population occurs from mid April to mid June. Spawning and larval rearing techniques used for Japanese scallops were used for this species. Spawning was induced on twelve occasions with a return of 10-40% from egg to veliger. The larvae were raised to 200μ in 22 days but none survived through metamorphosis.

ROCK SCALLOPS

Broodstock rock scallops were obtained locally. They were spawned on ten occasions by intermuscular injections of 0.4 ml of 2 x 10-5 molar solution of serotonin. Spawning occurred in 80% of males and 25% of females. Mean development from fertilized egg to veliger was 30%. Feeding regimes for the larvae were the same as described for P. yessoensis and metamorphosis occurred at 215-220µ in 23 days after spawning when larvae were raised at 16°C. Both static and downwelling systems have proven to be successful for spat settlement. At the present time we have 5-10,000 spat that measure 1-5 mm in shell diameter.

SEA SCALLOPS

Broodstock sea scallops were obtained from Passamoquoddy Bay at the mouth of the Bay of Fundy and were shipped to us from the Biological Station in St. Andrews, N.B. Two shipments were received in July 1984. Spawning was achieved by thermal shock on four occasions and larvae were raised at 12, 14, 16, and 18°C at larval densities of 10, 5, 2, and 1 larvae/ml. Best growth occurred when larvae were raised at a density of 1 larva/ml at 14°C. At present we have about 50,000 larvae at the setting stage.

One matrix feeding experiment was undertaken with sea scallop larvae. Ten day old larvae, mean shell length 136µ, were added to 2,000 ml beakers that had 1,800 ml of sea water to give a concentration of 1 larva/ml. The beakers were placed in a water bath and the temperature maintained at 14°C, salinity was 28°/$_{oo}$. They were fed a variety of algal diets and air was bubbled into half the beakers to keep the algae suspended. The experiment was run for ten days in October 1984.

Larvae grew fastest when fed a mixture of Tx and CC in beakers that had no air bubbled in them. They grew 40 µ in ten days or 4µ/day. Larvae fed only Iso or Tx in beakers with no air had the next fastest growth rate but only grew 1.5 µ/day (Table 1).

An interesting observation was the poor growth and heavy mortalities in beakers that had air bubbled through them. Air is customarily bubbled into all our cultures to help keep algal foods in suspension. Poor growth and survival of larvae may have been due to too much turbulence which interfered with the ability of the larvae to swim and feed or to minute toxic substances in the air supply. Filters have now been added to all air lines to prevent possible mortalities from this source.

DISCUSSION

Considerable progress was made in 1984 in our scallop breeding project. Methods were perfected to condition and spawn adult scallops of four

species. Extensive experimentation with algal foods showed the best diet for scallop larvae was a mixture of Tx and CC and this produced growth rates in Japanese scallop larvae that exceeded those reported in the literature (Kang et al. 1982). Larvae of three species, Japanese, rock and sea scallops, were raised to metamorphosis and some spat of all three species obtained.

A major problem experienced in the project was large mortalities of metamorphosing larvae and spat until they were about 1 mm shell diameter. We believe these mortalities were due mainly to nutrition and not disease. Although considerable progress was made in finding suitable diets for scallop larvae we probably have not found a diet that provides all the nutritional requirements during the larvae stage or one which enables larvae to build sufficient food reserves to enable them to survive metamorphosis. Another problem is that we have not found a good method to set larvae at metamorphosis. Other cultch material and methods may give a much higher survival at metamorphosis.

Research in these two areas is needed and in 1985 we plan to focus effort there to enable us to achieve the first goal of the project to produce large quantities of scallop seed for grow-out trials.

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Table 1. Comparison of growth of sea scallop larvae when fed different species of algae and held in beakers with air bubbled through the water and beakers with no air. Larvae were ten days old and had a mean shell length of 136 μ at the beginning of the experiment on October 19, 1984. Larval concentration at the start of the experiment was 1 larva/ml. Temperature was 14°C and salinity was 28 °/₀₀. Larvae were fed 20,000 algal cells/larva/day.

	With air			No air				
Food	Oct. 21	Oct. 23	Oct. 26	Oct. 21	Oct. 22	Oct. 23	Oct. 26	Oct. 29
CC		134.6	All cultures	150.0	142.5	146.7	147.0	145.5
Iso		136.0	on air	142.0	138.0	142.3	147.0	150.0
Tx		141.4	discarded	147.0	146.0	148.0	148.0	151.5
3H		138.0	because of	139.0	141.0	143.0	146.0	discarded
Tetra		136.0	heavy	137.5	136.5	134.5	discarded,	not growing
10 CC and 10Tx		139.0	mortalities	147.5	148.0	149.0	168.6	175.5

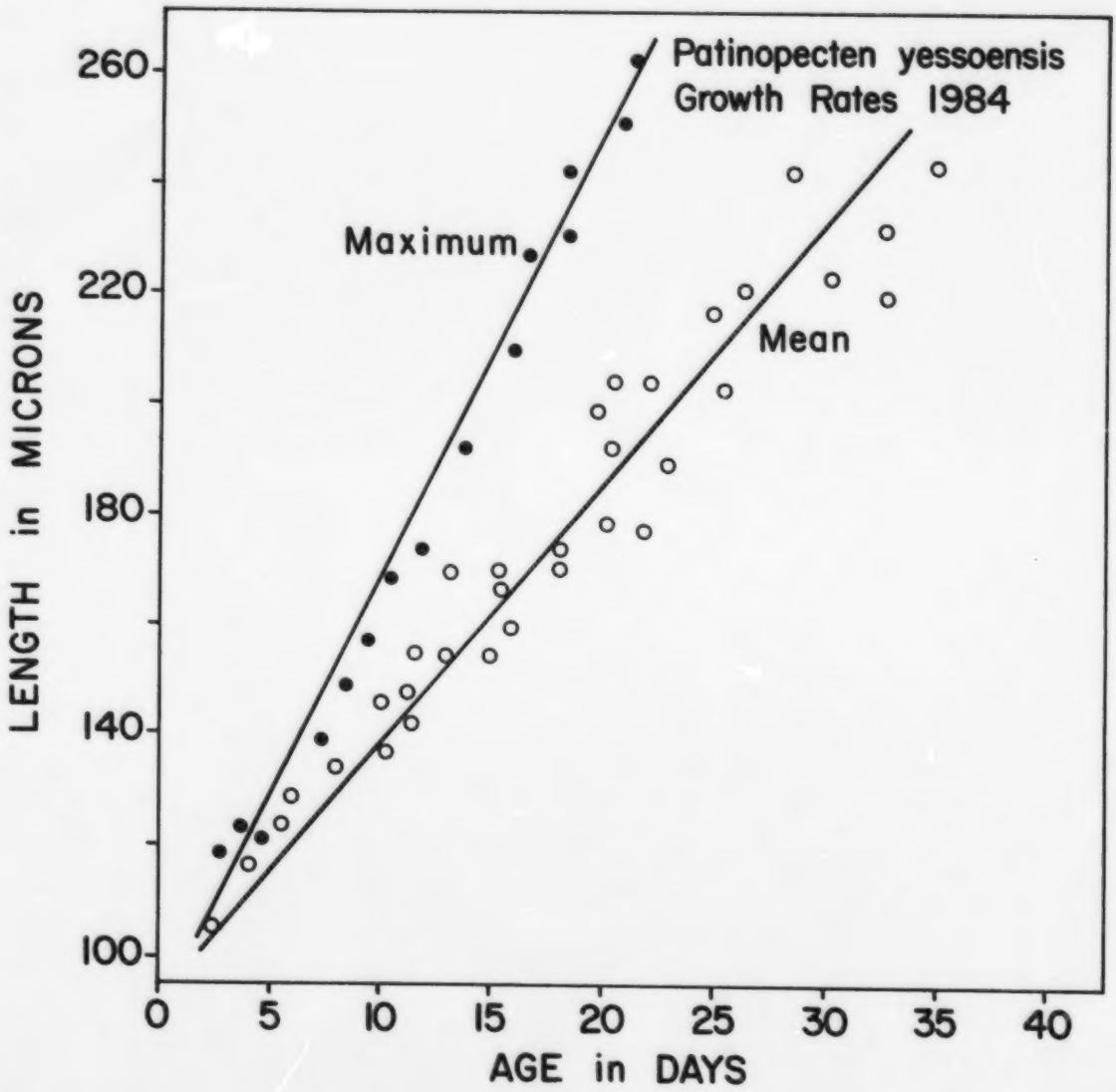

Fig 1 Maximum and mean growth rate of P. yessoensis larvae when raised in cultures at 15 C_2 in 1984. Linear regression for maximum growth, $Y = 84.22 + 8.19$, $r^2 = 0.988$ and for mean, $Y = 106.81 + 3.90$, $r^2 = 0.747$

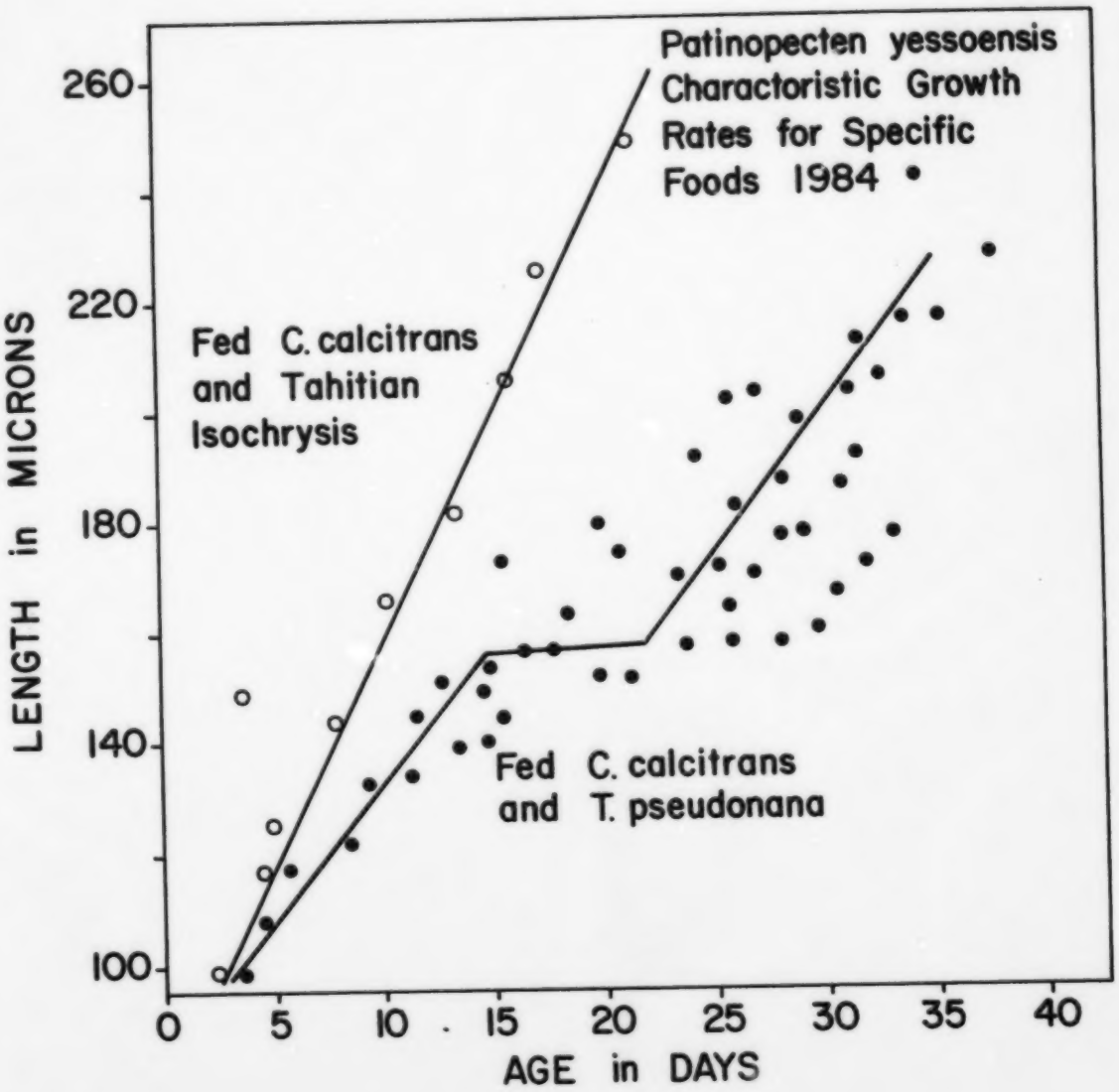

Fig 2 Growth rate of P. yessoensis larvae raised at 15 C and fed two different algal diets. Note the plateau in growth rate of larvae at a size of about 150 shell length when fed a mixture of C. calcitrans and I. pseudonana.